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VOLUME 1

MISSOULA VALLEY AQUIFER STUDY:
HYDROGEOLOGY OF THE EASTERN PORTION OF THE MISSOULA AQUIFER,
MISSOULA COUNTY, MONTANA

Prepared for

Water Development Bureau
Montana Department of Natural Resources and Conservation
Helena, Montana

by

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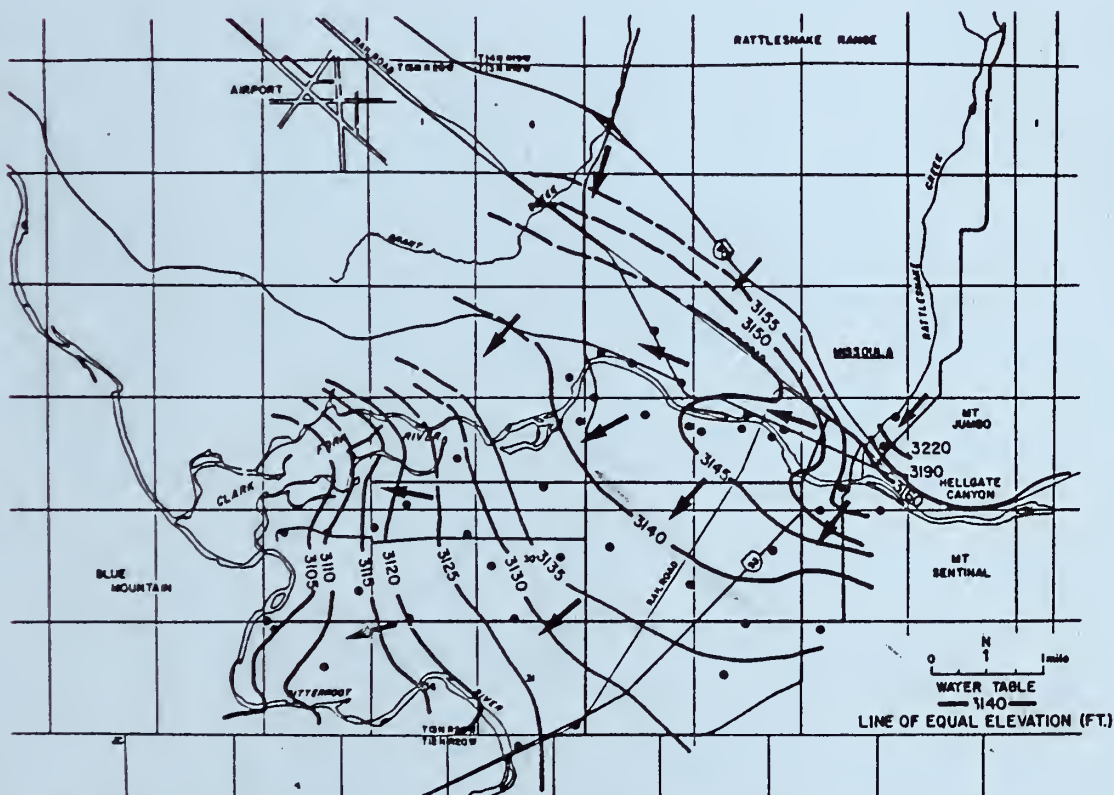


Figure 5.2: Water table map for June 1986. Arrows indicate general direction of ground water flow.

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MISSOULA COUNTY, MONTANA**

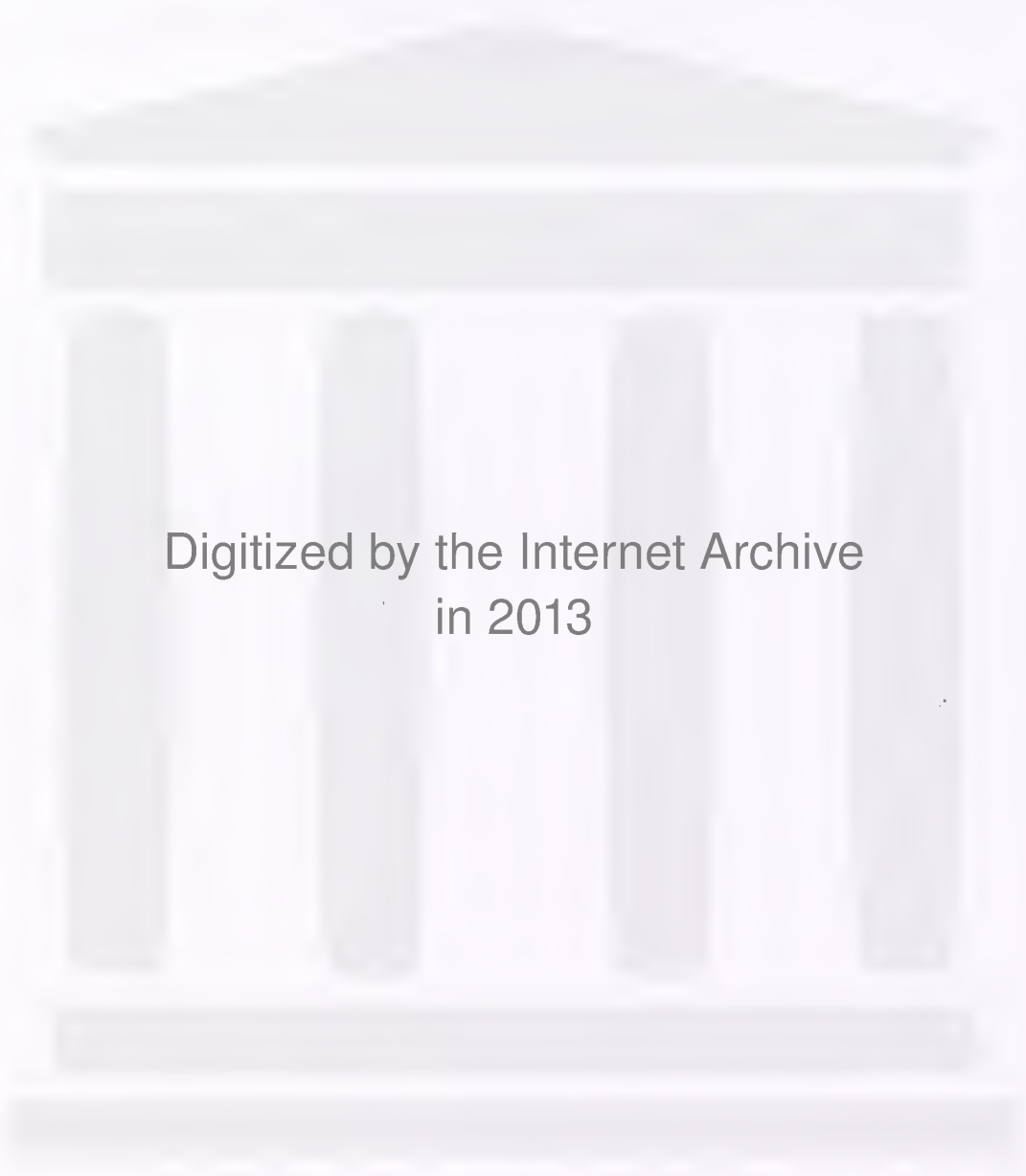
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EXECUTIVE SUMMARY

INTRODUCTION

The people of the Missoula Valley have used both surface and ground water for their municipal water supply since the mid-1900's. Rattlesnake Creek supplied surface water, and wells drilled into the valley floor have provided ground water. In the summer of 1983 giardia contamination forced the abandonment of the Rattlesnake Creek water supply system and valley residents became dependent solely on ground water, which comes primarily from the Missoula Aquifer.

The aquifer is unconfined and composed primarily of a 100 to 150 ft thick sequence of sand, gravel and cobbles. Below this surficial aquifer are over 2,000 ft of fine grained sediments overlying bedrock. The absence of any highly productive aquifers below the Missoula Aquifer together with the coarse grain size of the sediments at the top of the aquifer accent the need for careful management of this resource. This management must sustain sufficient water quantity and good water quality to meet the requirements of the Missoula area.

GOALS AND OBJECTIVES

This study has two goals. The first goal is to provide a scientific foundation upon which short and long term resource management decisions can be made. The second goal is to build on the pre-1985 data base to provide background for measuring existing anthropogenic effects and for assessing the potential for future problems. Specific objectives include:

1. Description of the physical properties of the Missoula Aquifer;
2. Initiation of a long term water level monitoring system for the aquifer;
3. Documentation of the seasonal variations in the water table;
4. Delineation of the areas recharging the aquifer, the general direction of ground water movement within the aquifer, and the locations of aquifer discharge areas;
5. Quantification of the volume of water recharging the aquifer and the volume removed by pumping and natural discharge;
6. Description of the chemical properties of the ground water and documentation of existing and potential sources of contamination; and
7. Development of a computerized numerical model of the aquifer to assess the impacts of natural and induced variation in recharge to the aquifer and in increased ground water removal by pumping.

STUDY RESULTS

A. Aquifer Stratigraphy

The Missoula Aquifer is apparently composed of three lithologic units which are identifiable throughout a large part of the aquifer. All contain

sand and gravel but have other features which determine their hydrologic character. The top unit (Unit One) is 10 to 30 ft thick, bouldery and generally lies above the saturated zone of the aquifer. The middle zone (Unit Two) is 40 ft thick and appears to have reduced water transmitting capacity due to its fine grained nature. The basal unit, Unit Three, is 50 to 100 ft thick, very coarse and currently yields large quantities of water to the many wells developed in it. Depending on how fine the grain size of Unit Two is, Unit Two's presence above the productive basal zone may protect underlying portions of the aquifer surface sources of contamination.

B. Hydraulic Properties

Overall, the Missoula Aquifer has a porosity of 0.20, a specific capacity of 0.12, a hydraulic conductivity of 18,200 gpd/ft² and a transmissivity of 1,152,000 gpd/ft. These values vary spatially depending on the presence and thickness of Unit Two and the thickness of the saturated portion of Unit One. As an example, hydraulic conductivity values are as high as 25,500 gpd/ft² for Units One and Three and about 8,000 gpd/ft² for Unit Two. Hydraulic conductivity and transmissivity values are apparently extremely high for Unit Three. Large production wells pump water from this unit with little drawdown.

C. Variations in Water Table Position

Five significant trends in the water table position are observed. The first is an annual water level rise which occurs between about March and June, and then a general decline until the following February or March. Second, the elevation of the spring peak water level at all wells decreased in 1987 from 1986. Minimum water table elevations were also lower in 1987 than 1986. Third the seasonal water table fluctuations decrease with increasing distance from the Clark Fork River or other influent streams. Fourth, wells located in the Missoula Aquifer, near the mouths of Grant Creek and possibly Rattlesnake Creek, have the largest annual fluctuations in water table elevation. Finally, the ground water system is also affected by flow in the Bitterroot River, as indicated by wells located near the Bitterroot River. The maximum water table elevation at these wells coincides with the spring runoff peak stage of the Bitterroot River.

Analysis of the long term water level trends in the valley indicate the effect of climatic influences and pumping stress on the aquifer. Hydrographs illustrate the longer term trend towards a general lowering of the valley water table since 1983. This trend is observed as a decrease in the elevations of yearly water table maxima and minima between 1983 and 1987. This record is too short to adequately assess whether a long term trend of net annual decline is actually occurring. This apparent lowering of the water table can be attributed to increases in withdrawal by Mountain Water Company starting in 1983 and to decreases in the Clark Fork River annual and peak discharges which also began in 1983 and continued through 1987.

D. Ground Water Movement and Recharge-Discharge Relationships

The same general pattern of ground water flow is observed through most of the year. North of the Clark Fork River, ground water moves away from the

channel and away from the northern aquifer boundary, where ground water from the Tertiary sediments and the alluvium in the Grant Creek and Rattlesnake Creek Valleys recharges the aquifer. The net result of recharge from these different sources is ground water migration parallel to the river channel and final discharge to the Clark Fork River north of the river's confluence with the Bitterroot River. South of the river ground water flows southwest towards the Bitterroot River and towards the confluence of the Clark Fork and Bitterroot Rivers.

Water recharges the Missoula Aquifer by leakage from the Clark Fork River, direct precipitation on the aquifer, inflow from the adjacent Tertiary Sediment and Bedrock Hydrostratigraphic Units, storm water runoff, septic system percolation and leakage from irrigation ditches. Leakage from the seven mile reach of the Clark Fork River in the valley constitutes over 90% of the recharge to the Missoula Aquifer.

Water discharges from the aquifer by evapotranspiration, as base flow to streams and by pumping. Evapotranspiration rates are quantified and assumed small. Ground water is discharged by pumping of wells owned by individuals, industrial users, and two private water companies, Mountain Water Company and Clark Fork Water Company (CFWC). On the average, these wells pump greater than nine billion gallons per year from the aquifer. The volume of natural discharge from the Missoula Aquifer was approximated (assuming no net change in storage) by subtracting estimated annual recharge to the aquifer from annual withdrawal from wells. Estimated natural discharge is 93% of the annual recharge.

Aquifer recharge exceeds the estimated ground water withdrawal by 15 times. The leakage of water through the bed of the Clark Fork River accounts for over 90% of annual recharge. Therefore, observed water table declines most likely reflect recent climatic changes which have caused reductions in recharge rates from the river and Tertiary sediments.

E. Water Quality

The ground water in the Missoula Aquifer is calcium bicarbonate water. Near the Clark Fork River, mineral content of ground water fluctuates seasonally in response to changes in water quality of the river. Throughout the rest of the aquifer, mineral content remains essentially constant at any one point but increases in the direction of ground water flow. Water is generally good quality and meets drinking water standards.

Water quality steadily decreases in the down gradient direction from the Hellgate Canyon area east and southeast toward the Bitterroot River. For example, total dissolved solids increase from a low of about 240 mg/l to a maximum of 358 mg/l over distances of four to five miles. This down gradient increase in total dissolved solids is probably caused by natural dissolution in the aquifer of carbonate minerals, such as calcite and dolomite. The increase in calcium, magnesium and bicarbonate concentrations correlates with the increasing levels of total dissolved. Concentrations of other major ions, such as sulfate, sodium, and chloride, do not increase consistently with increasing total dissolved solids.

Concentrations of chloride and nitrate also increase west and south west from the Clark Fork River along paths of ground water flow. These two ions are important indicators of pollution. Though concentrations do not exceed drinking water standards, above background values in isolated portions and in much of the western portion of the aquifer indicate ground water degradation occurs in these areas. The probable sources of contamination are wastes from seepage rings and septic tanks and from road salt in commercial areas. Testing of 98 wells for coliform bacteria resulted in 18 positive tests, an indication septic system waste is entering the ground water system. In addition to widespread changes in water quality, a number of isolated events, such as improper herbicide disposal, have affected portions of the aquifer and illustrate the vulnerability of the aquifer to pollution.

F. Ground Water Flow Modeling

Significant progress was made in defining the distribution of aquifer properties and boundaries and in understanding the interaction between the Clark Fork River and the ground water system. Efforts to construct and calibrate a transient model of ground water flow through the Missoula Aquifer were unsuccessful. Future modeling efforts will be used to describe the responses of the aquifer to variations in Clark Fork River recharge and to pumping by Mountain Water Company; additional data are required to develop the next model.

CONCLUSIONS AND RECOMMENDATIONS

The results of this two year study lead to the following conclusions:

1. The Missoula aquifer is stratigraphically complex. It is composed of three units, the second of which is not always present. The upper most unit, Unit One, is 10 to 40 ft thick and is composed of interbedded boulders, cobbles and gravel. The middle zone, Unit Two, is composed of up to 40 ft of tan to yellow silt with sand and gravel. Unit Three, the basal unit, is composed of 50 to 100 ft of interbedded gravel, sand and silt.
2. The hydrologic properties of the aquifer reflect site specific stratigraphy and depositional environments. Values of hydraulic conductivity and transmissivity appear to decrease southwest of the Hellgate Canyon and Grant Creek area. Approximate hydraulic properties of the entire aquifer, assuming the aquifer is acting as one homogeneous unit, are a porosity of 0.20, specific yield of 0.12, hydraulic conductivity of 18,200 gpd/ft² and a transmissivity of 1,152,000 gpd/ft.
3. Changes in aquifer storage are indicated by water table variations. These fluctuations reflect seasonal changes in the quantity of recharge reaching the aquifer and in the rates of ground water withdrawal by pumping and by natural discharge. During 1985-1986, peak water table elevations throughout the valley were higher than peak elevations in 1986-1987. The water table low recorded in late winter was lower in 1987 than the previous year. These valley wide trends appear to have begun in 1983, when climatic conditions apparently changed, resulting in

less than normal Clark Fork River spring discharge and aquifer recharge. Also since 1983, the main water producer in the valley, Mountain Water Company, more than doubled its ground water pumping rate. As a result, a general lowering of the water table occurred at Mountain Water Company wells.

4. The Clark Fork River is a losing stream and seasonally recharges the aquifer over a four to six mile reach. Mass balance calculations show that the river accounts for 90 percent of aquifer recharge. Total aquifer recharge is 15 times greater than withdrawal from Mountain Water Company wells, Clark Fork Water Company wells and approximately 4,700 individual wells. Based on these data, the apparent valley wide decline in the water table since 1983 is a result of a reduction in recharge caused principally by lower than normal flow in the Clark Fork River.

5. North of the Clark Fork River, the direction of ground water flow is strongly influenced by recharge from the boundary foothills on the north and from the Clark Fork River. Flow in this part of the aquifer parallels the river and moves west until it passes the Reserve Street area, where it turns south to discharge to the Clark Fork River below its confluence with the Bitterroot River. In the area of Missoula south of the Clark Fork River, ground water flows south and southwest to discharge to the Bitterroot River and, seasonally, to the lower reaches of the Clark Fork River.

6. The water quality of the aquifer is good and does not require treatment prior to use in most areas. The water is dominated by calcium and bicarbonate ions, is low in total dissolved solids (less than 500 mg/l) and is similar in chemistry to the Clark Fork River. The presence of chloride and nitrate concentrations which are elevated above natural background levels suggests degradation from anthropogenic sources is occurring. Injection of storm water was found to increase chloride concentrations at the water table beneath storm drains. The disposal of sewage by seepage rings or drain fields appears to be degrading water quality in portions of the valley as both nitrate and chloride concentrations are elevated in areas served by septic systems. Fortunately, concentrations do not exceed drinking water standards. However, coliform bacteria and fecal coliform bacteria have been found in individual water supplies in numbers which exceed drinking water criteria. The aquifer is extremely vulnerable to contamination because it is unconfined and consists of generally coarse material.

7. An attempt to numerically simulate the aquifer's complex stratigraphy and recharge-discharge relationships was unsuccessful. The computer model could not be calibrated using field data and then independently verified with a second set of field data. Problems were viewed as being partially attributable to inadequate definition of recharge rates from the Clark Fork River and of the distribution of aquifer properties.

The conclusions listed above imply that the Missoula Aquifer is an aerially extensive, thin, unconfined system which is geologically complex and

vulnerable to contamination. It is Missoula's sole source of water and an irreplaceable resource. Protection of the Missoula Aquifer requires continuing long term observation and management. The following recommendations are based on the conclusions outlined above:

1. Maintain a long term water level observation network.
2. Along with a water level monitoring network, a water quality monitoring network should be established. Approximately 30 wells located throughout the aquifer and finished in various aquifer units should be sampled four times a year.
3. The development of a numerical model of the aquifer should be continued. Long term management of the aquifer as the sole source of water supply for Missoula and surrounding areas requires the ability to test the effects of increased pumping and changes in recharge rates prior to their occurrence.

It is the goal of these recommendation to provide the citizens of Missoula with the facts needed to make educated management decisions regarding the future of their source of potable water. Halting data collection and further work on model development would be short sighted and could result in poor planning and crises in managing this critical resource.

ACKNOWLEDGMENTS

Though this work is authored by one person it could not have been completed without the contributions of many individuals and groups. David Nimick provided final editorial work and his effort is greatly appreciated. Researchers Bill Clark, Bill Morgan, Mike Pottinger, Karen Wogsland, Bill Peery and Ross Miller contributed significantly to the project. Jim Bigley assisted with instrumentation and Bill Thompson, Linda Angeloni and Cas Smith helped with data processing. Preliminary research results were also discussed with the staff of the Missoula City County Health Department and local hydrogeologists and hydrologists.

This project received invaluable support from the Missoula City County Health Department, Mountain Water Company, the Missoula County Surveyors Office and hundreds of residents of Missoula who allowed access to their property and wells.

The citizens of Montana funded about one half of this effort through the Water Development Grant Program of the Montana Department of Natural Resources and Conservation. The Missoula County Commissioners, through the Missoula City County Health Department, also assisted significantly with financial support. Additional research funds from the US Environmental Protection Agency, the Montana Water Resources Research Center and the University of Montana's Excellence Fund supported portions of this effort.

I sincerely appreciate all support.

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CHAPTER 1

INTRODUCTION

The people of the Missoula Valley have used both surface and ground water for their municipal water supply since the mid-1900's. Rattlesnake Creek supplied surface water and wells drilled into the valley floor have provided ground water. In the summer of 1983 giardia contamination forced the abandonment of the Rattlesnake Creek water supply system and valley residents became dependent solely on ground water, which comes primarily from the Missoula Aquifer.

The Missoula Aquifer consists of 50 to 150 feet (ft) of coarse sand and gravel which directly underlie the valley bottom. Currently the aquifer supplies over 9.7 billion gallons of water annually. The valley is surrounded by hills and mountains where bedrock and fine grained Tertiary aquifers produce only limited quantities of ground water. Therefore the Missoula Aquifer is considered the valley's primary source of water. In June 1988 the aquifer met EPA sole source aquifer criteria. Currently, water from the Missoula Aquifer requires no treatment and the supply of water appears adequate. However the ability of the ground water system to sustain continued development and resist wide spread contamination is unclear.

This study has two goals. The first is to provide a scientific foundation upon which short and long term resource management decisions can be made. The second is to build on the pre-1985 data base such that existing impacts can be measured and the potential for future problems can be assessed. Specific objectives include:

1. Description of the physical properties of the Missoula Aquifer;
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6. Description of the chemical properties of the ground water and documentation of existing and potential sources of contamination; and
7. Development of a computerized numerical model of the aquifer capable of assessing the impacts of natural and induced variation in aquifer recharge and increased ground water pumping.

During its two year time span, this large project was divided into a number of smaller studies. All have been under the direct supervision and direction of the author. They include graduate and undergraduate thesis research at the University of Montana by Meyer (1985), Clark (1986), Morgan (1986), Sendler (1986), Bayuk (1986), Peery (1989), Pottinger (1988), Wogsland (1988), and Ver Hey (1987). Ground water modeling was performed by Pottinger

(1988) and research associate Brick (1987). These recent works rely upon the earlier work of Geldon (1979) and McMurtrey and others (1965). Many of these studies are summarized in this report. The reader is urged to consult these referenced reports for additional detailed information. Other portions of the study have not been published as separate reports. Pertinent data from these project activities are included in the appendices.

This report is organized into two volumes. Volume 1 contains the main text, figures and tables. Volume 2 is the appendix to the report.

The chapters in Volume 1 focus on the seven specific objectives listed in the beginning of this chapter. Chapter 2 briefly describes the study site. Chapter 3 addresses the geometry, stratigraphy and hydrologic properties of the aquifer. Chapter 4 describes the ground water monitoring program used in this project and reports on the observed seasonal fluctuations of the water table. Chapter 5 quantifies aquifer recharge, aquifer discharge and directions of ground water flow. Chapter 6 describes water quality in the aquifer and summarizes three case studies of aquifer contamination. Chapter 7 describes the attempt at modeling the physical ground water system in an effort to evaluate future effects on the aquifer. Chapter 8 presents conclusions and recommendations.

Volume 2 contains supporting material for chapters three, four, five and six.

CHAPTER 2

STUDY AREA SETTING

Numerous authors have prepared general site descriptions of the Missoula Valley. The one presented here is taken primarily from the work by Clark (1986).

PHYSIOGRAPHY AND GEOMORPHOLOGY

The Missoula Valley is approximately 35 mi² in size. It is bounded by the Rattlesnake Hills on the north, the Sapphire Mountains on the east, the Bitterroot Mountains on the south and, on the west, by a low plateau in the vicinity of the Johnson-Bell airport (Plate 1). The Missoula Valley is the eastern part of a long intermontane depression trending WNW from the city of Missoula (Figure 2.1).

The topography of the valley floor is relatively flat, but slopes gradually downward from the bounding highlands towards the northwest, where the Clark Fork River leaves the valley. There are two major river terraces on the valley floor. Twenty foot scarps separate the terraces from each other and from the floodplains of the Clark Fork and Bitterroot Rivers (Geldon, 1979). Another valley floor feature is McCally Butte, a 200 ft high bedrock outlier located in the floodplain of the Bitterroot River.

The Missoula Valley is drained by the Clark Fork and Bitterroot Rivers. The Clark Fork River enters the valley from the east through the 1,500 ft deep Hellgate Canyon (Plate 1). The river flows westward for about seven miles, meeting the Bitterroot River at Kelly Island. The Clark Fork River has a gradient of 10.4 ft/mi. The Bitterroot River enters the valley in the south central portion of the study area. It flows northwest for 4.5 mi at a gradient of 5.2 ft/mi before joining the Clark Fork River. Several smaller streams enter the valley from the surrounding highlands, including Rattlesnake Creek, Grant Creek and Pattee Creek (Plate 1).

CLIMATE

The climate of the Missoula Valley is semiarid. Winter is dominated by Pacific maritime air, which occasionally is displaced by cold continental air draining through the Clark Fork Valley. Annual precipitation averages 13.29 inches (NOAA, 1987) (Figure 2.2). Peak precipitation occurs in May and June. The least precipitation occurs in February and March. High intensity convective storms in July and August may also contribute significant precipitation.

SURFACE WATER HYDROLOGY

The Clark Fork River is gaged above and below Missoula by the U.S. Geological Survey (USGS) (Figure 2.3). The gaging station above Missoula is located near Bandman Bridge, 2.8 mi east of Missoula. The station below

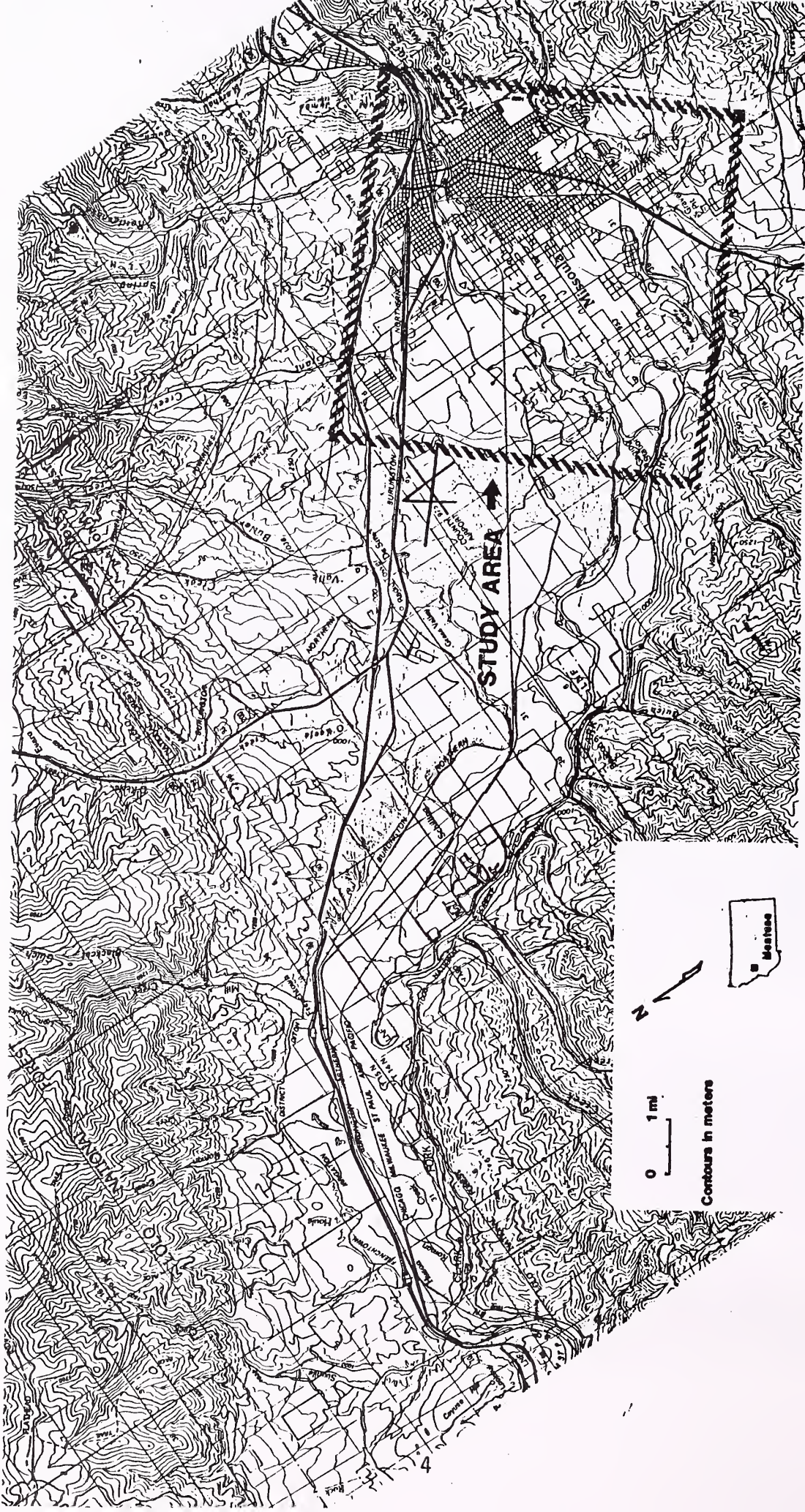


Figure 2.1: Location of the study area and the eastern two-thirds of the Missoula-Ninemile Valley (Huson to Missoula).

Missoula Valley Precipitation

Yearly Totals

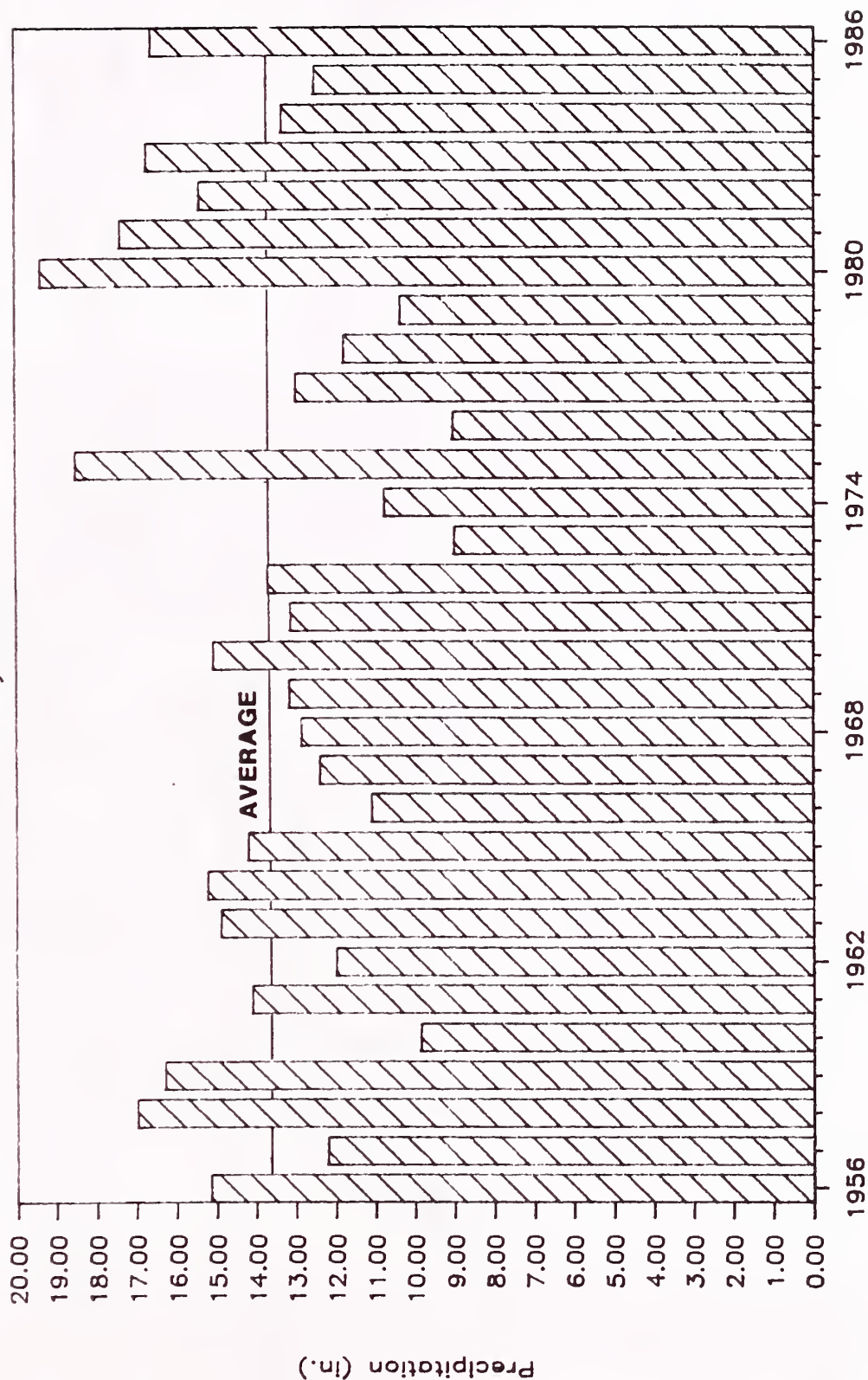


Figure 2.2: Yearly precipitation totals, 1956 to 1986 (NOAA, 1987).

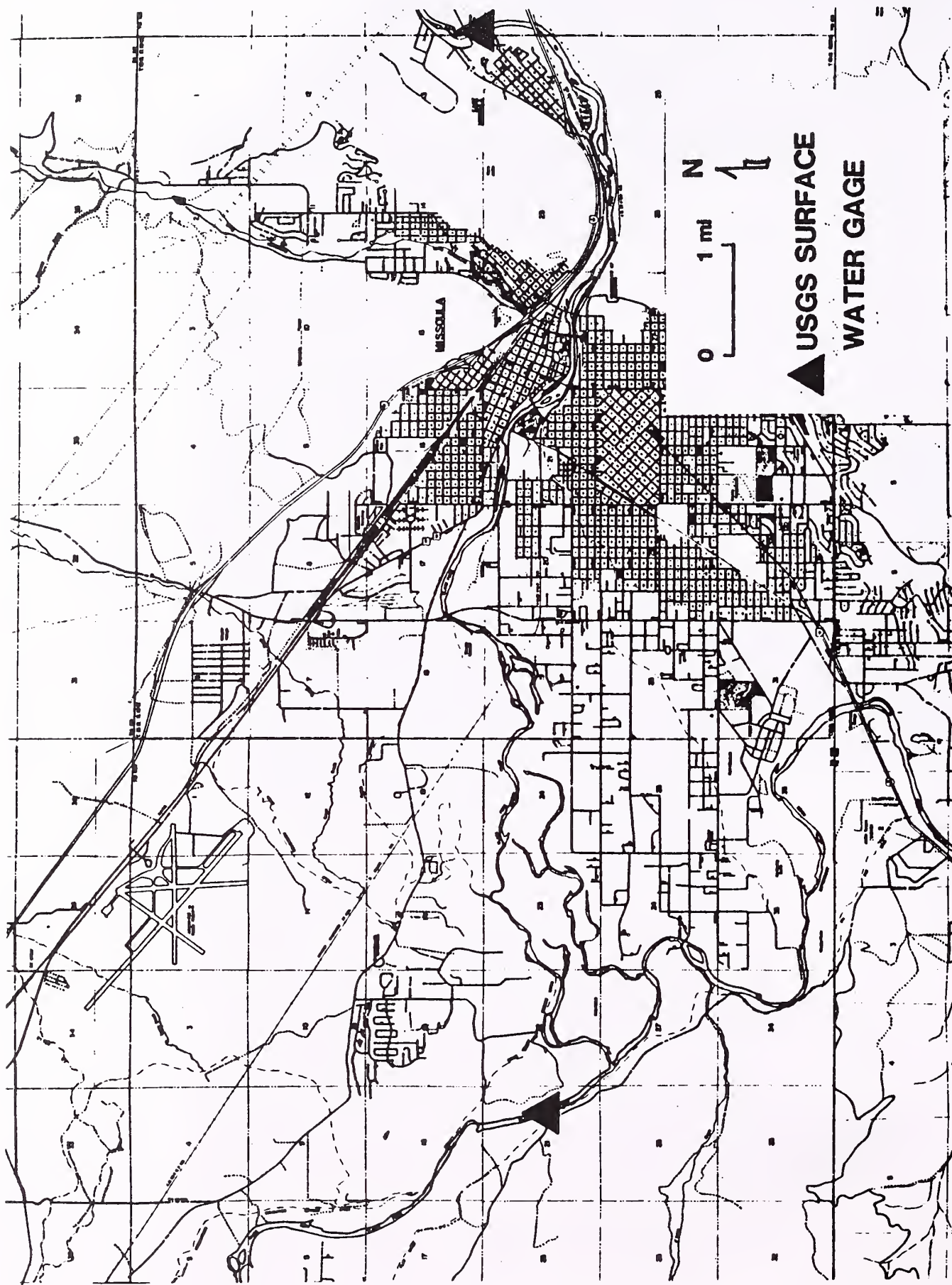


Figure 2.3: Location of the USGS surface water gaging stations.

Missoula is located 1.0 mi downstream of the confluence with the Bitterroot River, 4.5 mi west of Missoula. Both have been gaged continuously since 1929.

The drainage area of the Clark Fork River above the upper gaging station is 5,992 mi². Based on 57 years of data (1930 to 1986), mean annual discharge is 3,051 cubic feet per second (cfs) (USGS, 1987) (Figure 2.4). The maximum recorded daily flow was 32,300 cfs on June 21, 1975. The minimum flow of 340 cfs occurred on September 27, 1937. Average monthly discharges indicate the general response of the river to spring runoff. The lowest mean monthly flow (1,596 cfs) occurs in December while spring rains and snowmelt cause the maximum mean monthly flow (8,740 cfs) in June (Figure 2.4). Peak discharge in 1985 was 8,680 cfs on May 25 and minimum discharge was 826 cfs on August 1. In 1986, the river peaked at 12,900 cfs on June 1 and had its minimum discharge of 979 cfs on August 20 and 21.

The gaging station below Missoula records the combined flow of the Clark Fork and Bitterroot Rivers. Mean annual discharge is 5,547 cfs (USGS, 1984) (Figure 2.5). A maximum discharge of 52,800 cfs occurred on May 23, 1948; the minimum was 388 cfs on January 18, 1933. Mean monthly discharge varies from 2,045 cfs in December to 20,160 cfs in June (Figure 2.5). A 1985 peak discharge of 19,900 cfs occurred on May 25; the minimum discharge was 1,180 cfs on August 1. In 1986 a peak of 32,100 cfs was observed on May 31 and a minimum flow of 1,620 cfs on August 21. The Bitterroot River contributes about 3,000 mi² to the 9,003 mi² drainage area above this gage.

The Bitterroot River was gaged independently from 1898 to 1905 at a bridge four miles southwest of Missoula. For this period of record, mean annual discharge was 3,260 cfs (USGS, 1975). Geldon (1979) estimates the mean annual discharge for the Bitterroot River as 2,339 cfs, or about 40% of the total flow of the Clark Fork River below the confluence of the rivers.

Rattlesnake Creek was gaged from 1959 to 1967 at the Vine Street Bridge in Missoula. The drainage area is 79.7 mi². Mean annual discharge for the period was 110 cfs (USGS, 1975). Geldon (1979) estimated the mean annual discharge for the period from 1959 to 1977 as 135 cfs by extrapolating the Rattlesnake Creek gaging data with Clark Fork River gaging records for the entire period.

Pattee Creek and Grant Creek have not been gaged by the USGS. Geldon (1979) estimated discharge for Pattee Creek by comparing drainage area and precipitation data for these ungaged drainages with Rattlesnake Creek data. Mean annual discharge is 13 cfs for Pattee Creek. du Breuil (1983) gaged Grant Creek and estimated the mean annual discharge at 30 cfs.

GEOLOGY

The sediments of the Missoula Valley are continental clastic deposits (Figure 2.6). The floor of the valley is covered by alluvial and lacustrine sediments of Quaternary age, 1.6 million years to the present. These deposits are described in more detail in Chapter 3.

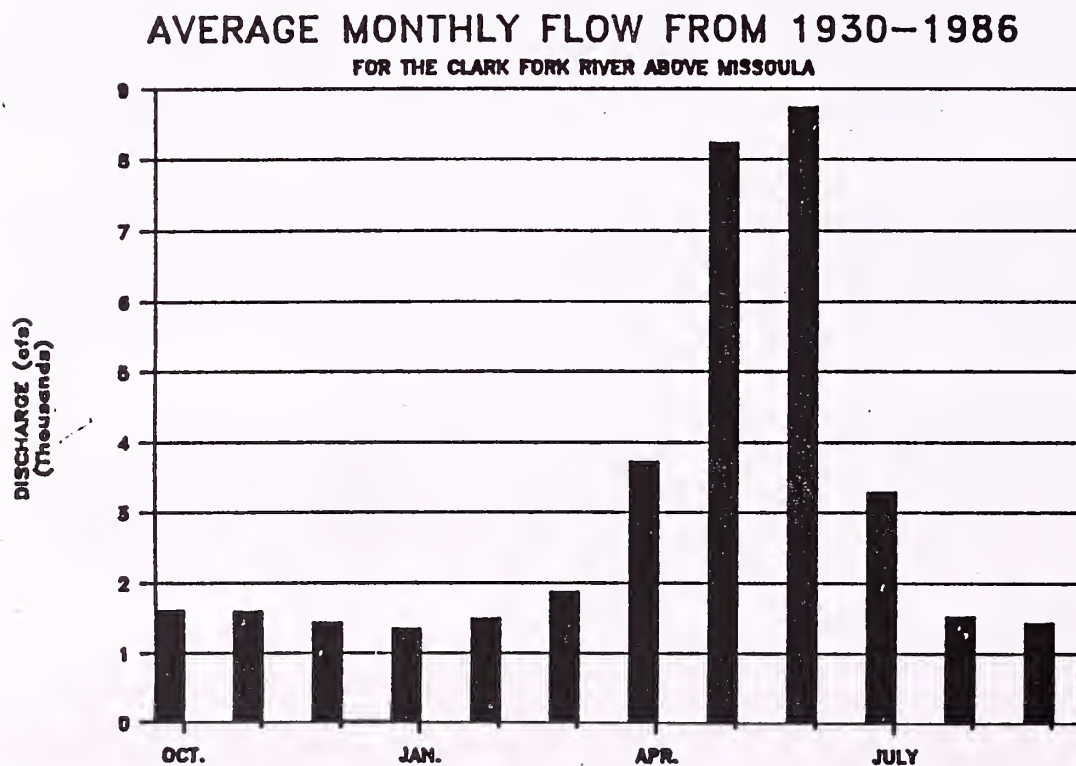
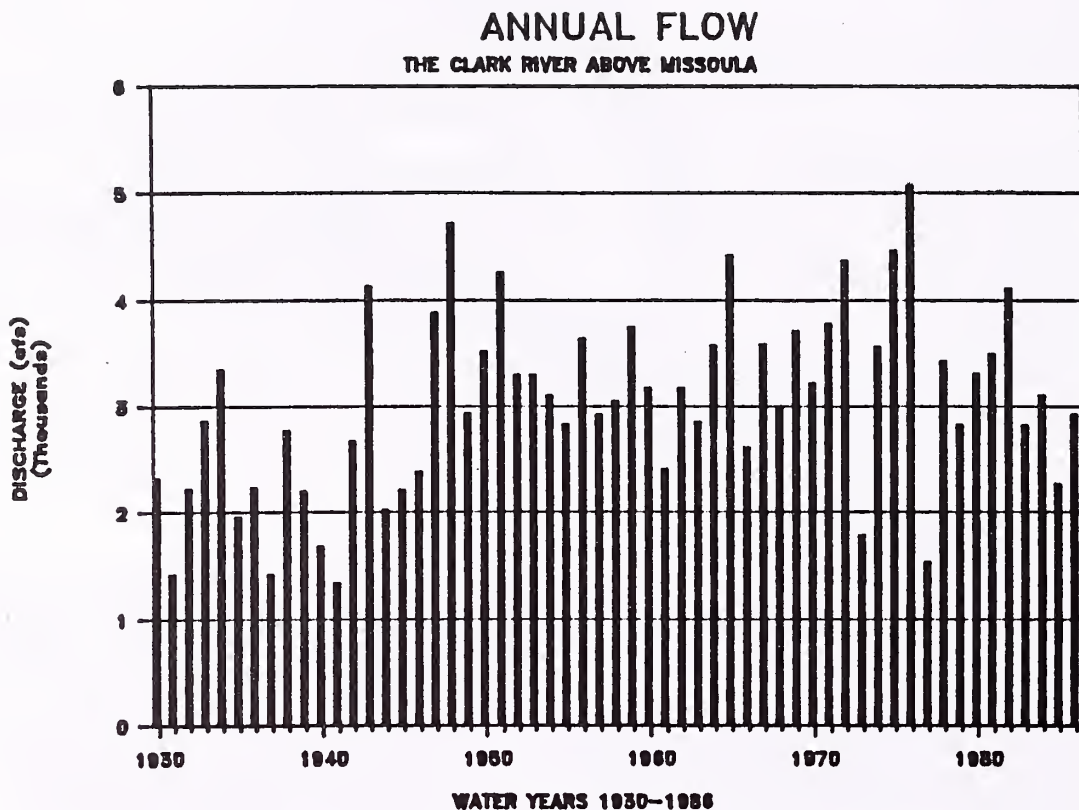


Figure 2.4: Average (top) and average monthly flow (bottom) for the Clark Fork River at Bandman Bridge above Missoula.

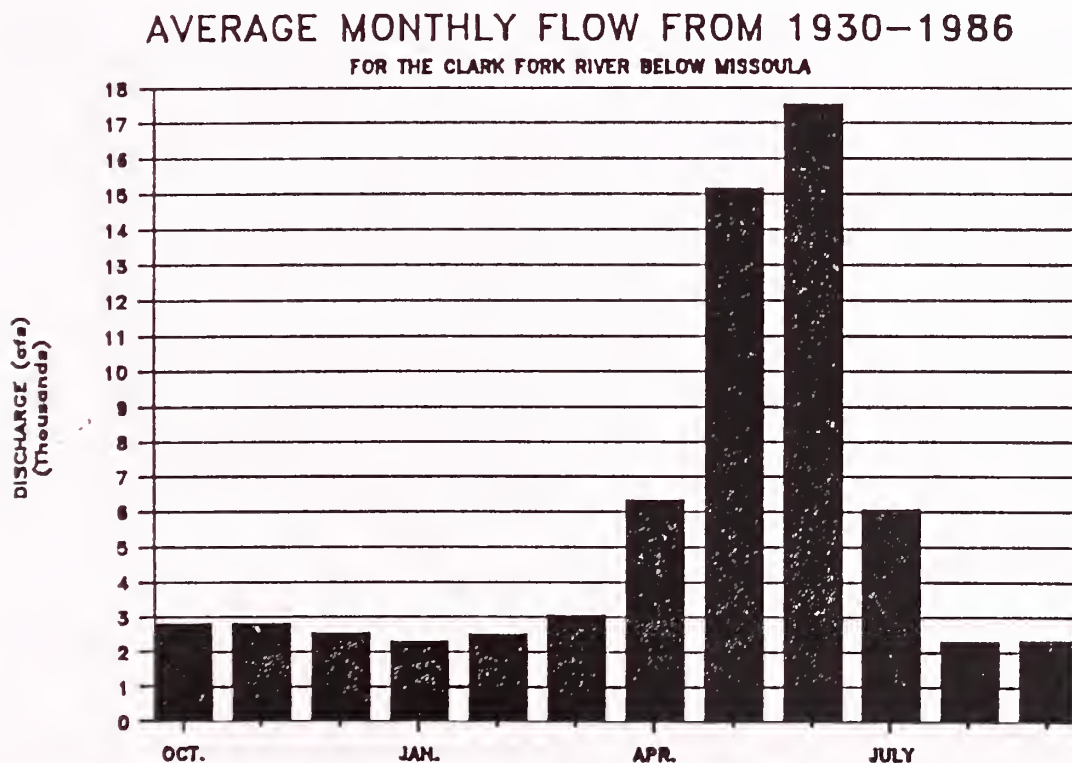
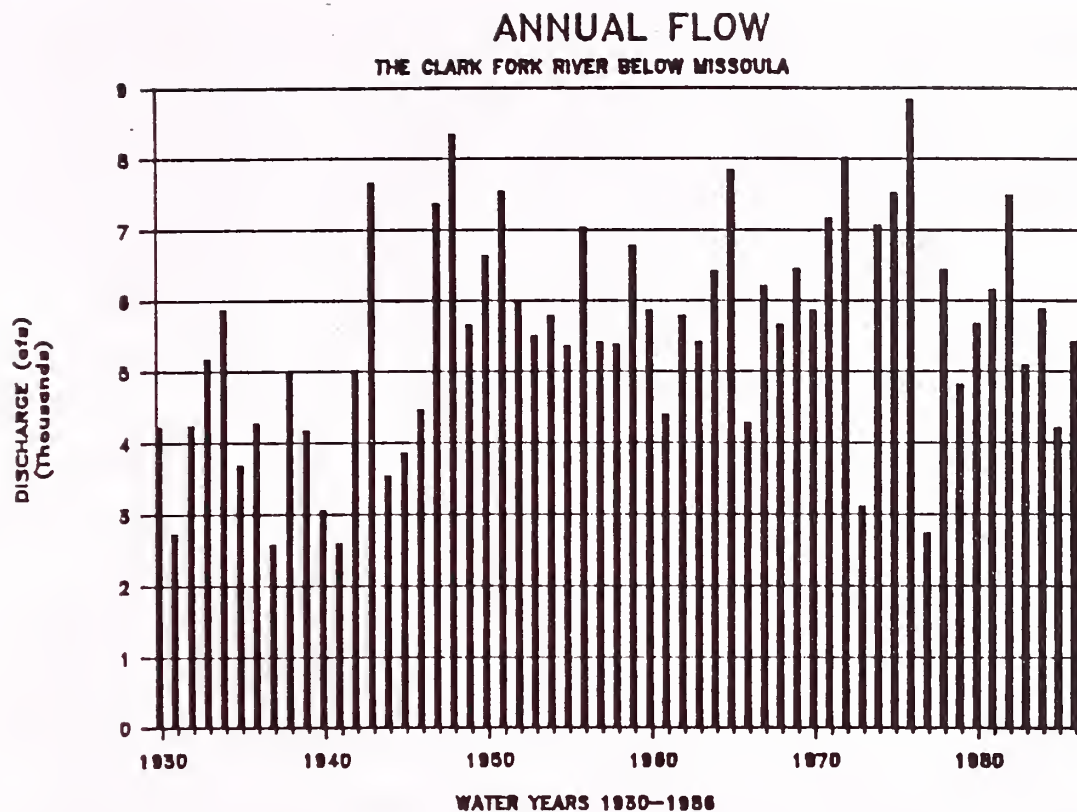


Figure 2.5: Annual (top) and average monthly (bottom) flow for the Clark Fork River at the USGS gage below Missoula.

The low foothills surrounding the valley floor are principally composed of fine grained sediments deposited when the basin was internally drained during the Tertiary period, 43 to 5.3 million years. Although up to 2,500 ft of Tertiary sediments are preserved in the valley (McMurtrey and others, 1965), surface exposures are infrequent and poor around the valley margins. The sediments range in size from clay to coarse gravel and unconformably overlies Precambrian Belt Supergroup metasediments. Tertiary sediments are subdivided into three stratigraphic units:

1. Fanglomerates (pre-Renova Formation equivalent) which are believed to be limited to the basin's margins, ? to 43 million years;
2. Fine grained ash-rich sediments (Renova Formation equivalent) which underlie the valley floor, 43 to 20 million years; and
3. Coarse clastic sediments (Sixmile Creek Formation equivalent) which are found locally in the foothills and may be overlying the Renova Formation beneath the valley floor, 20 to 5.3 million years.

A north-south diagrammatic section of the valley showing Tertiary and Quaternary deposits is presented in Figure 2.7. The Cenozoic geology of the Missoula area has been described in detail by McMurtrey and others (1965), Kuenzi and Fields (1971), Fields (1981), Thompson and others (1982), Wehrenberg (1983) and Fields and others (1985).

Mountain ranges surrounding the valley, including Mount Jumbo and Mount Sentinel, are composed of Precambrian metasediments of the Belt Supergroup, 0.8 to 1.6 billion years.

The intermontane depression, of which the Missoula Valley is part, is believed to have formed as a result of horizontal extension after Laramide thrusting, which occurred between late Cretaceous and middle Eocene time, 97.5 to 52 million years ago (Fields and others, 1985). The horizontal extension resulted in normal faulting parallel to the faces of Mount Jumbo and Mount Sentinel and in the formation of the Clark Fork Fault, which is exposed on the north side of the valley (Figure 2.6).

GROUND WATER HYDROLOGY

Missoula Valley residents use ground water from three sources: fractured Precambrian Belt Supergroup rocks, Tertiary Renova equivalent sediments, and the coarse alluvium which is exposed at the surface of the valley floor (Table 2.1). Use of the fractured bedrock and the Renova equivalent aquifers is generally restricted to the valley margins. The shallow sand and gravel deposits below the valley floor are the principal source of ground water.

The Precambrian bedrock surrounding the valley is generally a poor aquifer. The rock is essentially impermeable and water flows only through fractures. Wells generally yield about one gallon per minute (gpm). However, in the Hayes Creek area, a well yielded 17 gpm during a four hour aquifer test (Bayuk, 1986). Wells finished in bedrock range in depth from 38 to over 1,000 ft. Geldon (1979) reported an average specific capacity of 0.11 gallons per minute per foot of drawdown (gpm/ft). Analysis of driller's reports in the

DIAGRAMMATIC SECTION ALONG RUSSELL STREET

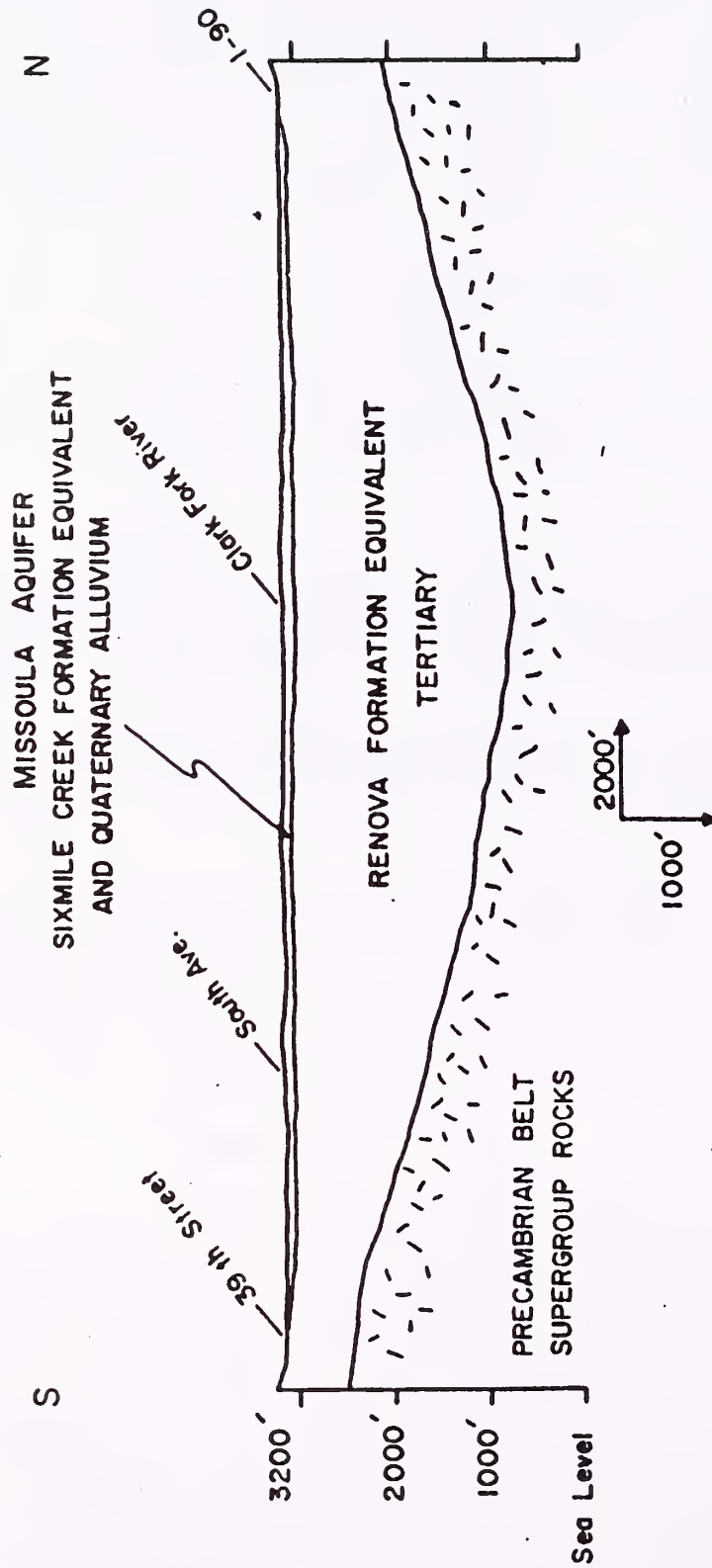


Figure 2.7: Schematic north-south cross-section of the Missoula Valley. Location shown on Figure 2.6 (Clark, 1986).

Hayes Creek area indicates specific capacities vary from 0.5 to 35 gpm/ft. Bayuk (1986) noted that yield decreases with increasing well depth.

Table 2.1
Hydrostratigraphic Units of the Missoula Valley

Hydrostratigraphic Unit	Age	Thickness (ft)	Description
Missoula Aquifer	Miocene (?) to Recent	150	Sand, gravel and boulders with some silt and clay. Clasts well rounded. Yields up to 7,000 gpm.
Tertiary Sediments	Late Eocene to Early Miocene (?)	2,500 to 3,500	Clay with interbedded and embedded sand and gravel. Clay is blue, gray, brown, tan and red. Local coal and volcanic ash. Yields up to 40 gpm but averages 25 gpm.
Precambrian	Precambrian	greater than 10,000	Quartzite, red and green argillite and carbonates. Water is from fractures. Yields up to 17 gpm, but averages 1 gpm.

Renova equivalent sediments which occur on the valley flanks and beneath the Missoula Aquifer locally comprise a second low yielding aquifer. Discontinuous lenses of sand and gravel, usually less than 10 ft thick, provide water under artesian conditions to wells, generally at less than 20 gpm (Geldon, 1979). Barclay (1986) studied the hydrogeology of the Ninemile Valley and reported the average yield of 32 wells finished in Renova sediments to be 11.3 gpm with a range of 0.5 to 45 gpm. Finstick (1986) found similar values for Renova equivalent sediments in the Bitterroot Valley near Victor. However, well MWC3 on South Avenue (Plate 1) penetrates 2 three foot zones of sand and gravel in the Renova equivalent sediments which yielded 75 gpm when the well was developed. Geldon (1979) reported hydraulic conductivities (K) averaging 165 gallons per day per foot squared (gpd/ft²), specific capacities of 0.51 gpm/ft and a storage coefficient of 10⁻⁴. Barclay (1986) reported an average hydraulic conductivity of 300 gpd/ft² with a range of 0.08 to 1,900 gpd/ft² for Renova equivalent sediments in the Ninemile Valley.

Both the Precambrian and Tertiary units yield small quantities of water to wells. They are utilized for domestic supplies where other more productive sources are usually not available. In some small tributary valleys, saturated alluvium yields small quantities of water (Barclay, 1986). The saturated coarse sand and gravel material which directly underlies the valley floor is

of principle interest to the majority of water users in the Missoula basin. These coarse sediments include Pleistocene and Recent alluvial sediments and may also include an upper portion of the Sixmile Creek Formation. Although these sands and gravels may range in age from Miocene to Recent and be part of different geologic formations, they have similar hydrologic properties. Therefore, these sands and gravels are grouped into one hydrostratigraphic unit called the Missoula Aquifer. This aquifer yields over 9.7 billion gallons of water annually to wells which supply the city and over 4,700 individual dwellings. Geldon (1979) reported that the Missoula Aquifer has an average hydraulic conductivity of 5,100 gpd/ft², specific capacities of over 3,000 gpm/ft and transmissivities (T) of over 1,000,000 gpd/ft. Aquifer storage coefficients range from 0.11 to 0.35. It is the Missoula Aquifer that is the focus of this report.

Geldon (1979) prepared maps of maximum and minimum water table positions in the Missoula Aquifer. He noted seasonal fluctuations in the water table with highs in the first half of July and lows around March 1. Both McMurtrey and others (1965) and Geldon (1979) recognized the importance of the Clark Fork River in recharging the surficial sand and gravel system. They interpreted flow directions to be away from the Clark Fork River. Flow is to the west on the north side of the river and to the southwest on the south side. Geldon (1979) estimated the average discharge of water through the main part of the Missoula Aquifer to be 5.1×10^6 ft³/d at a velocity of 6.2 ft/d. He attempted a water balance for the aquifer and concluded that discharge from the aquifer was exceeding recharge during 1977 and 1978 by about 21,000 acrefeet (acft).

WATER QUALITY

Water quality in the Missoula Aquifer is good and well below all drinking water standards. Juday and Keller (1978), the Montana State Water Quality Bureau (WQB), Hydrometrics (1984) and Mountain Water Company have analyzed water quality in the valley.

Ground water in the Missoula Aquifer is calcium-bicarbonate type. It is moderately hard, as expressed by the sum of calcium and magnesium ion concentrations. Total dissolved solids are usually less than 350 milligrams per liter (mg/l). Chloride concentrations are less than 10 mg/l and sulfate is less than 30 mg/l. The pH ranges from 6.8 to 8.5. Geldon (1979) reported an average calcium to silica ratio of 2.3, which implies a relatively rapid circulation of ground water in the aquifer. The ratio decreases southwestward away from the Clark Fork River as the ground water flows farther from the recharge area. Seasonally, wells near the Clark Fork River and downtown Missoula show 60% fluctuations in total dissolved solids in response to similar changes in the Clark Fork River (Hydrometrics, 1984). The WQB collects an annual ground water sample in the Missoula Valley.

The Mountain Water Company monitors water quality in the valley's municipal wells. Fifty-four bacteriological samples are collected each month (about 2 samples per well per month). Every 4 years MWC tests its wells for inorganic chemical constituents. They also sample the Clark Fork River periodically.

Water found in the Tertiary sediments is a calcium-bicarbonate type. Total dissolved solids are generally less than 500 mg/l (Geldon, 1979; Juday and Keller, 1978). Iron concentrations typically exceed the 0.30 mg/l drinking water standard. Based on measured calcium to silica ratios, Geldon (1979) concluded that ground water circulated through the Tertiary sediments longer than shallower water did in the Missoula Aquifer.

Bayuk (1986) reported water quality data for the Precambrian bedrock aquifer underlying the Hayes Creek area. The water is calcium-bicarbonate type with total dissolved solids ranging from 290 to 350 mg/l. Water quality is characteristic of a bedrock aquifer near its highland recharge area. It is anticipated that deep water below the Missoula Valley in mineralogically similar bedrock would be considerably higher in total dissolved solids.

CHAPTER 3

GEOMETRY, STRATIGRAPHY AND HYDROLOGIC PROPERTIES OF THE MISSOULA AQUIFER

INTRODUCTION

One of the specific objectives of this research effort was to describe the physical and hydrologic properties of the Missoula Aquifer. These properties include transmissivity, storage, porosity and hydraulic conductivity as well as the variation in aquifer thickness and internal heterogeneity. This chapter starts by presenting data on the aerial and vertical extent of the aquifer material. The second portion defines the hydraulic properties of the aquifer.

AQUIFER GEOMETRY

The Quaternary deposits shown on the geologic map (Figure 2.6) indicate the surface extent of the Missoula Aquifer in the study area. The aquifer covers approximately 35 mi². The vertical extent of the aquifer can be approximated from the hundreds of driller's reports and well logs on file at the Missoula office of the Montana Department of Natural Resources and Conservation. Summaries of these well logs are presented in Appendix 3A. Morgan (1986) and Clark (1986) attempted to delineate the aquifer base and the internal stratigraphy of the aquifer from these records. Much of the following description is taken from Morgan's and Clark's research.

Aquifer geometry and stratigraphy were evaluated by interpretation of geologic logs recorded on driller's reports and from the collection and description of cuttings taken from nine wells drilled during the course of this project. Field inspection of excavations and road cuts in which the unsaturated portion of the aquifer was exposed were also examined.

Interpretation of the aquifer base proved more difficult than anticipated. Less than 20 wells were inferred to fully penetrate the aquifer. Most of these were Mountain Water Company wells, which are concentrated in the eastern portion of the valley.

Two criteria were used to determine the base of the aquifer. The first is a downward change, seen in the driller's geologic log, from a coarse sand and gravel sequence to a sequence dominated by silts and clays. This transition presumably separates coarse grained sediments which yield water from the underlying fine grained Tertiary sediments which do not yield significant amounts of water.

The second criterion is based on well design and yield data recorded in driller's reports. Total depths and perforated intervals of wells were used to identify portions of the aquifer with higher transmissivity. These data were then used in conjunction with yield and drawdown information reported by drillers. Domestic wells penetrating the Missoula Aquifer produce 10 to 100

gpm with only a few feet of drawdown. In contrast, wells finished in Tertiary sediments produce only a few gallons per minute with tens of feet of drawdown.

Seismic refraction work conducted by Clark (1986) was unsuccessful in defining the base of the aquifer, which was assumed to be 150 to 200 ft below land surface. Apparently the acoustic impedance between the sand and gravel deposit and the underlying Renova equivalent sediments is too low to be recognized with the equipment used (Bison Signal Enhancement Seismograph Model 1570B), and/or the interface is deeper than what the equipment can record.

Figure 3.1 presents data from driller's reports for three wells. Two of the wells penetrate the aquifer in the Missoula Valley. A contrasting third well is from the Ninemile area and is finished in Tertiary sediments similar to those found on the flanks of the Missoula Valley and beneath the Quaternary sand and gravel of the valley floor.

Figure 3.2 presents the interpreted depth from land surface to the base of the aquifer. Although data are insufficient to construct an isopach map, cross sections could be constructed from well data to indicate the general position of the aquifer base (Figures 3.3 to 3.7). Well data used for these cross sections are summarized in Appendix 3A. Based on the cross sections, the Missoula Aquifer averages between 110 and 140 ft in thickness but ranges from 92 to 237 ft thick. These thickness values include the unsaturated portion of the aquifer.

The saturated thickness of the aquifer ranges from 50 to 120 ft in the most of the valley. The thinner sections occur in the central and northern portion of the valley. Depth to water is typically 50 to 70 ft in the central portion of the basin and at its northern contact with the Tertiary sediments. The water table is closest to the surface (10 to 30 ft) adjacent to streams and in the southwestern portion of the basin.

The Missoula Aquifer is thickest (over 200 ft) at the merger of the Grant Creek Valley and the main Missoula Valley. In the spring when, Grant Creek is actively recharging the aquifer, the saturated portion of the aquifer near the mouth of the Grant Creek Valley is 130 to 150 ft thick with one site recorded as 197 ft (Pottinger, 1988).

AQUIFER STRATIGRAPHY

Morgan (1986) developed a composite picture of the stratigraphy of the Missoula Aquifer from his extensive review of driller's reports and construction of cross sections (Figures 3.3 to 3.7). The stratigraphy noted by Morgan is based on his interpretation of often sketchy driller's logs and has not been confirmed by a detailed drilling program. He described four stratigraphic units. The lowest unit correlates with the Tertiary Sediment Hydrostratigraphic Unit and the other three are interpreted as parts of the Missoula Aquifer Hydrostratigraphic Unit (Table 2.1). These upper three units are renumbered and described below (Table 3.1).

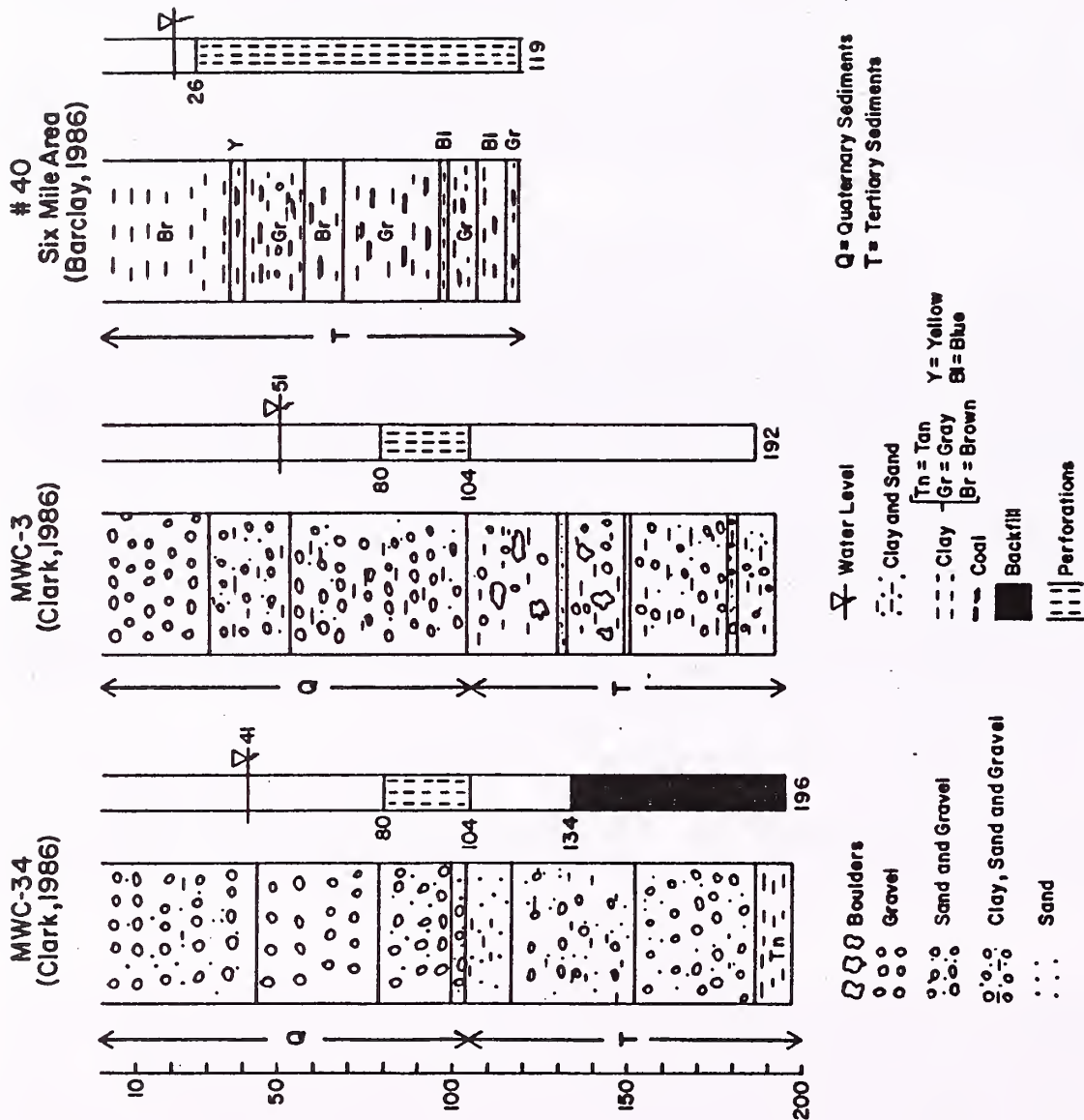


Figure 3.1: Well logs and interpreted contact between Quaternary and Tertiary sediments.

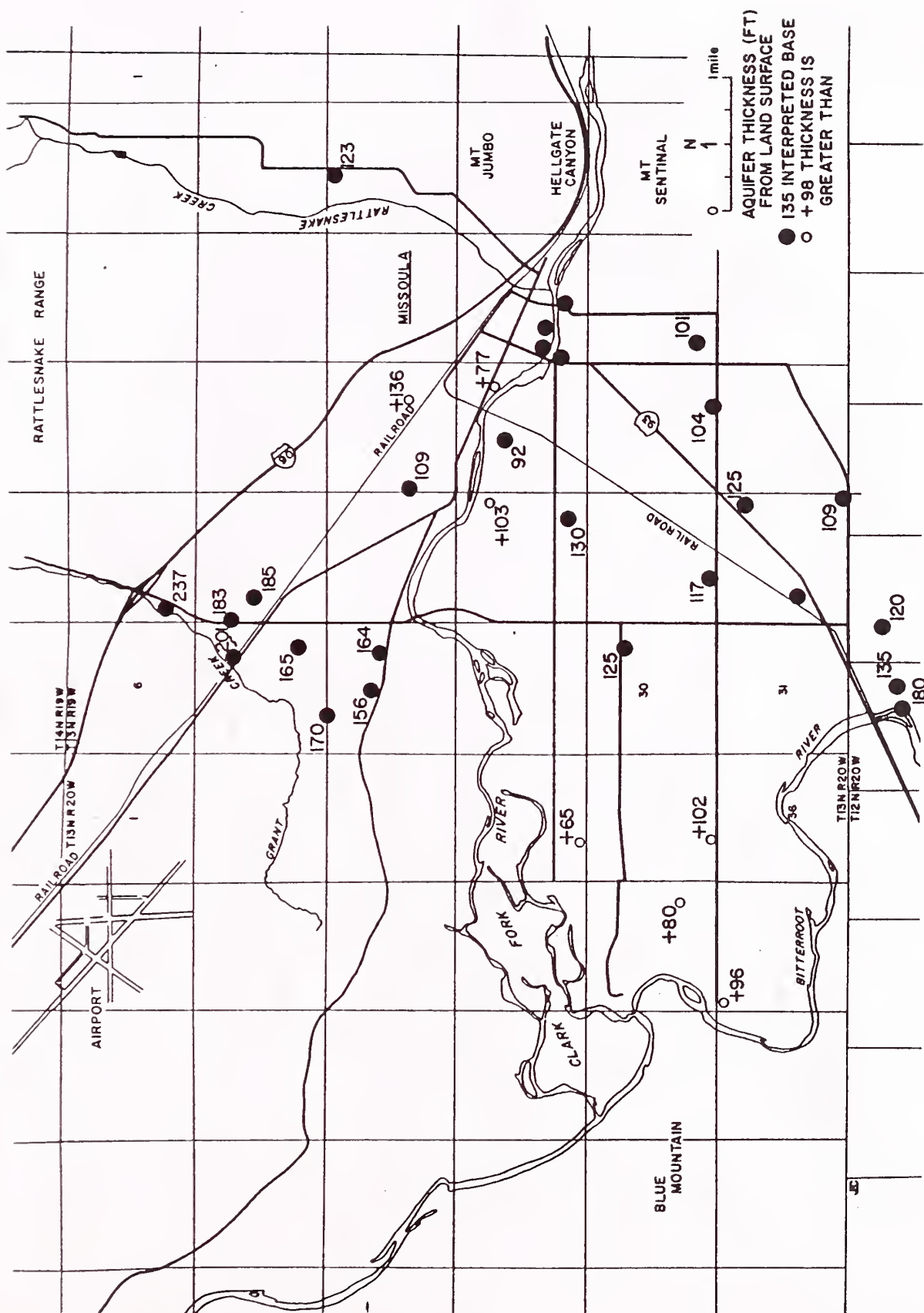


Figure 3.2: Interpreted depth to the base of the Missoula Aquifer.

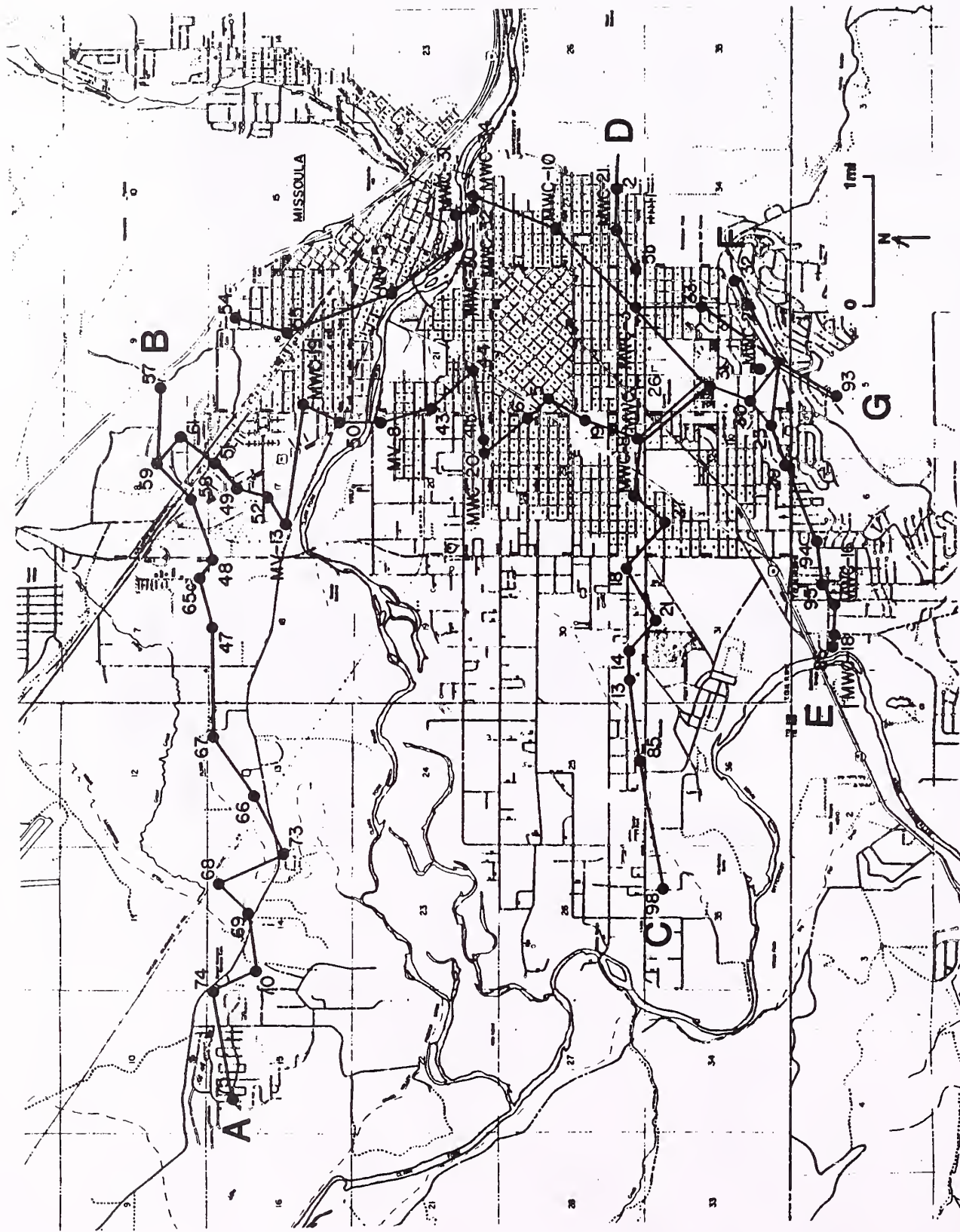


Figure 3.3: Location of geologic cross sections (after Morgan, 1986).

CROSS SECTION BASED ON WELL LOGS

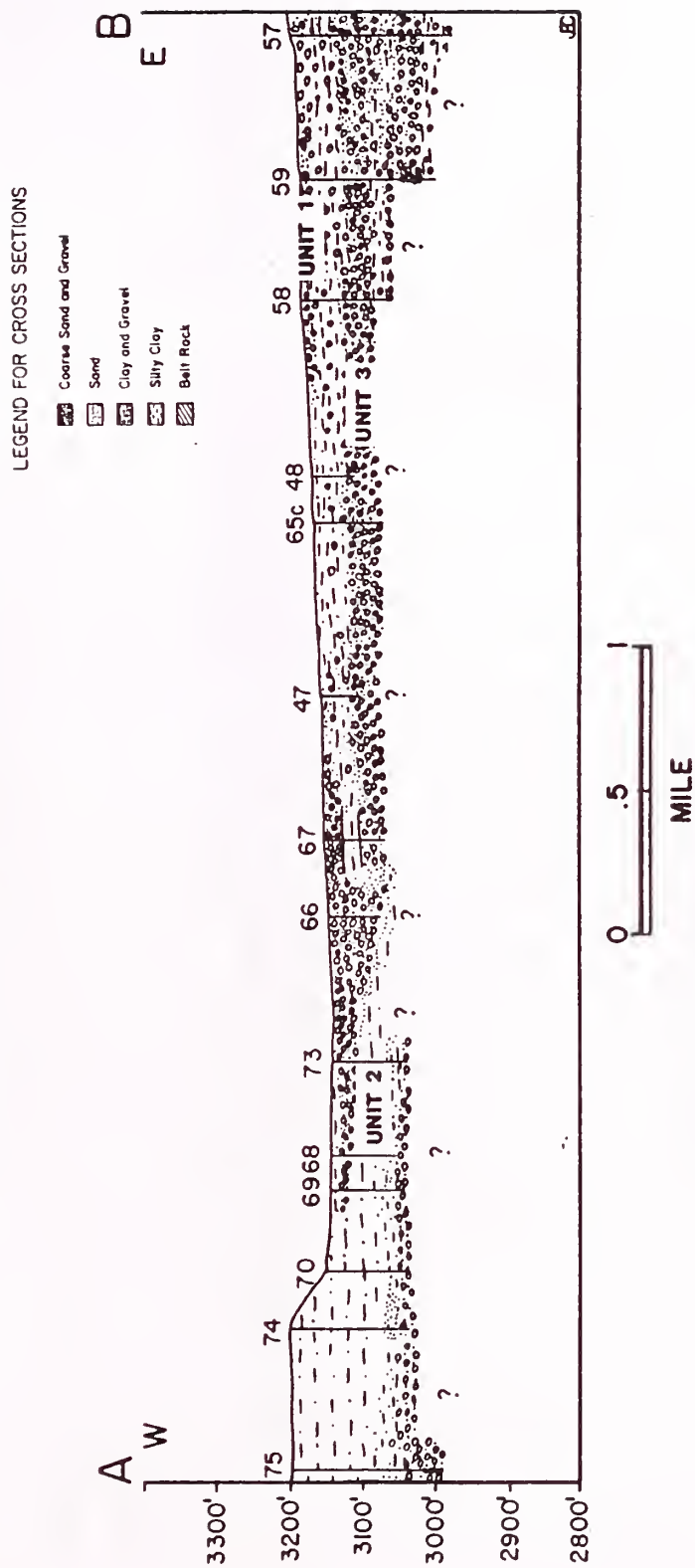


Figure 3.4: Cross section A-B (after Morgan, 1986).

CROSS SECTION BASED ON WELL LOGS

LEGEND FOR CROSS SECTIONS

-  Coarse Sand and Gravel
-  Sand
-  Clay and Gravel
-  Silty Clay
-  Bed Rock

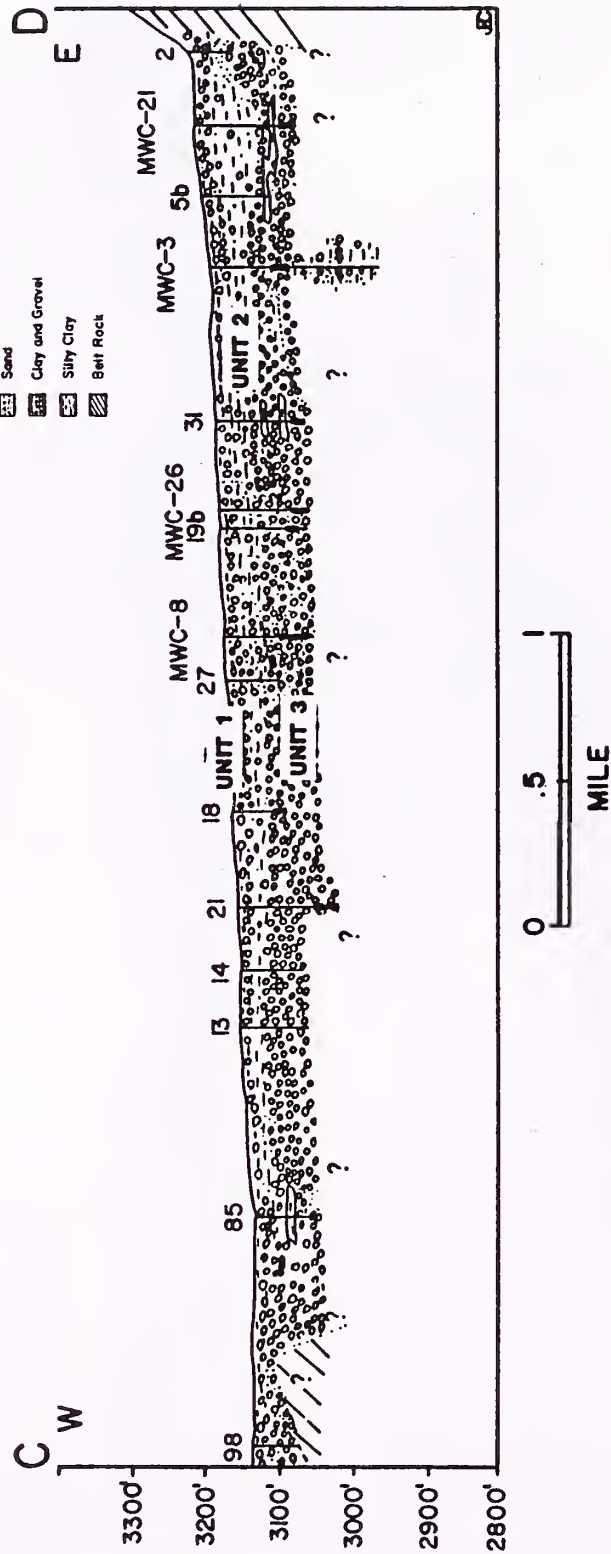


Figure 3.5: Cross section C-D (after Morgan, 1986).

CROSS SECTION BASED ON WELL LOGS

LEGEND FOR CROSS SECTIONS

-  Coarse Sand and Gravel
-  Sand
-  Clay and Gravel
-  Silty Clay
-  Belt Rock

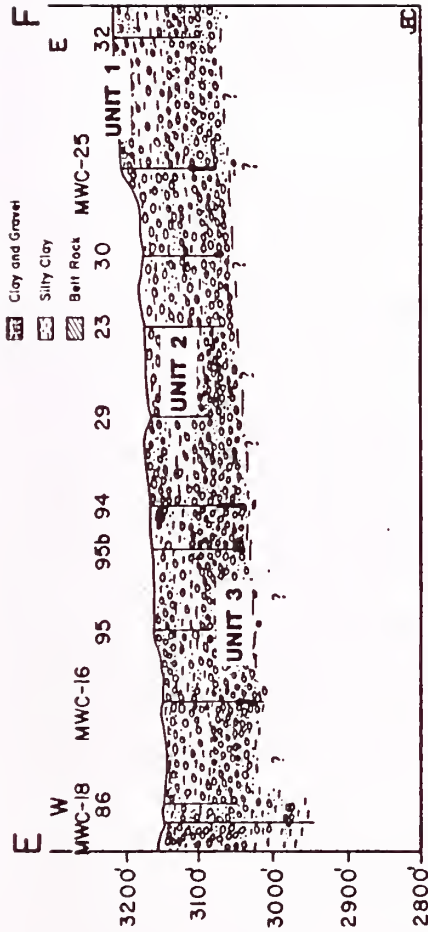


Figure 3.6: Cross section E-F (after Morgan, 1986).

CROSS SECTION BASED ON WELL LOGS

LEGEND FOR CROSS SECTIONS

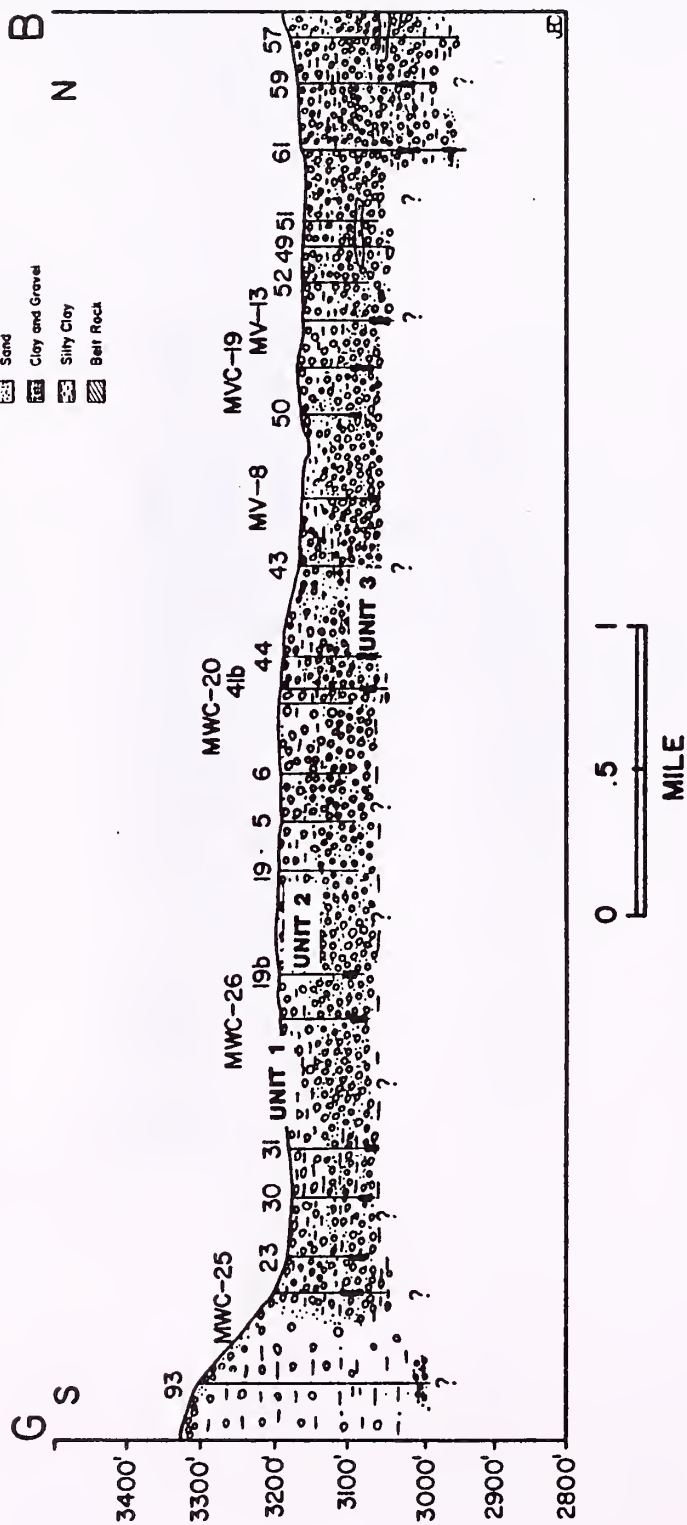
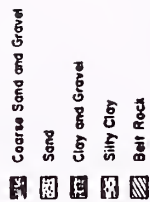


Figure 3.7: Cross section G-B (after Morgan, 1986).

TABLE 3.1
Stratigraphic Zones of the Missoula Aquifer

Unit One:	Interbedded boulders, cobbles and gravel with sand, silt and some clay. Thickness from 10 to 30 ft. Found at land surface.
Unit Two:	Tan to yellow, silty sandy clay with local layers of coarse sand and gravel. Thickness averages 40 ft in the center of the basin (Figure 3.5) to 130 ft in the northwest section of the study area (Figure 3.7). Absent in places.
Unit Three:	Interbedded gravel, sand, silt and clay. Unit seems to be coarser at the bottom. Thickness varies from 50 to 100 ft. May include part of the Sixmile Creek Formation.

Unit One forms the surface of much of the valley floor. It is composed of 10 to 30 ft of large boulders, cobbles, sand and silt and lacks the abundant fine sediments of Unit Two (Figures 3.4 to 3.7). The large cobbles and boulders are characteristic and are difficult to drill through. Unit One was probably deposited by large aggrading river systems fed by glacial meltwaters during the last stages of the Pleistocene.

To determine the size range and uniformity of aquifer material, sieve analyses were conducted on four 50 lb sediment samples collected from the upper unsaturated portion of the aquifer (Clark, 1986) (Table 3.2). Two samples came from a vertical face of the excavation for the University of Montana Stadium at the northeast corner of the campus and two from a gravel bar in the Clark Fork River between the confluence of Rattlesnake Creek and the University Walking Bridge. All four samples are very coarse and very poorly sorted. Using the modified Wentworth grain-size scale, 90% of the sediment is at least the size of coarse sand. Mean diameters are in the coarse to very coarse pebble range. Values of the uniformity coefficient and inclusive graphic standard deviation for all 4 samples indicate that each sample is very poorly sorted (Folk, 1980).

Saturation of Unit One generally occurs only beneath and adjacent to streams and in the southwestern corner of the aquifer. The rest of this unit is above the saturated zone and therefore does not yield water. The shallow ground water found in saturated portions of Unit One is more likely to be affected by contaminants infiltrating from the surface than water found in deeper units.

TABLE 3.2
Grain Size Data from Sieve Analyses for
Unit One, Missoula Aquifer

	Sample 1	Sample 2	Sample 3	Sample 4
Location	excavation for UM stadium		gravel bar Clark Fork River	
Depth of sample (ft)	5-15	15-20	0-0.5	0.5-1.0
Effective diameter (mm)	0.50	0.55	4.0	0.55
Mean diameter (mm)	19.8	53.5	79.7	60.3
Uniformity coefficient	44	91	30	104
Inclusive graphic standard deviation	2.31	2.92	3.18	2.74

Unit Two generally consists of a yellow silty sandy clay with interbedded gravel and sand lenses. Well logs do not contain sufficient information to determine detailed stratigraphy, but drillers report a predominance of tan clay, sand and gravel. Drillers note the existence of clay in this unit from the return of cloudy tan to pink water with the drill cuttings. However, cuttings of sand and gravel are also returned continuously during drilling of some wells. Based on its lithology and the presence of the tan clay, Unit Two is probably related to deposition of Pleistocene Glacial Lake Missoula sediments which outcrop in the northwestern part of the study area (Figure 3.4). In fact, finer portions of the drill cuttings look very similar to Glacial Lake Missoula sediments. During the repeated filling and draining of Glacial Lake Missoula, a complex sequence of alluvial fans, stream channels and deltas interfingered with lake sediments on the flanks and floor of the valley. Over 100 ft of fine grained lake sediments overlies gravel in the western portion of the valley near Huson and appear to interfinger with the western edge of the Missoula Aquifer (Figure 3.4). Unit Two is discontinuous in some areas of the aquifer and may have been replaced by coarser fluvial deposits (Figure 3.4 and 3.7). Few wells are developed in Unit Two because Unit Three has a higher transmissivity.

Unit Three is dominated by coarse grained sediments, especially at the base of the unit. Tan fine grained sediments are interlayered with sand and gravel. The ratio of fine to coarse material must be low because wells pumping over 3,000 gpm are developed in this unit. Unit Three probably represents channel lag, point bar and floodplain deposits from a large fluvial network which developed over time. Morphologically similar deposits are found in the present Clark Fork River channel and floodplain. This large fluvial could have developed either in the Pleistocene or late Tertiary.

Grimestad (1977) observed similar stratigraphy west of the study area at the Stone Container Corporation mill near Frenchtown (Figure 2.1). He described a 25 to 35 ft thick sequence of sand and gravel at the surface; an underlying 60 to 125 ft thick sequence of mixtures and lenses of silt, sand, clay and gravel; and a basal 20 to 50 ft thick zone of sand and gravel resting on bedrock. This sequence of finer material sandwiched between coarser units correlates well with the three Missoula Aquifer units described previously. The thickness and pronounced finer nature of Grimestad's middle layer (compared to Unit Two) may be a result of either being farther from the northeast portion of the valley where high energy streams enter, or because it was lower in elevation and subject to longer periods of lake related deposition.

In summary, the Missoula Aquifer appears to be composed of three lithologic units which are identifiable throughout a large part of the aquifer. All contain sand and gravel but have other features which determine their hydrologic character. The top unit is bouldery but generally above the saturated zone. The fine grained component of the middle zone appears to have reduce water transmitting capacity. When it is present above this productive basal zone, it may protect portions of the valley's water supply from quick downward movement of contaminants through Unit One. The basal unit is very coarse and currently yields large quantities of water to the many wells developed in it.

HYDROLOGIC PROPERTIES

Important hydrologic properties of an aquifer include porosity, specific yield or storage, hydraulic conductivity and transmissivity. Characterization of these properties in the Missoula Aquifer was accomplished by reviewing the literature, interpreting driller's reports and conducting grain size analyses, permeameter experiments, and aquifer pumping tests. Clark (1986) describes the basic methods used to interpret aquifer properties and the following material has been largely taken from his work. Additional results of Morgan (1986) are included in the discussion of specific capacities.

All hydrologic analyses done in this study were based on the major assumption that the aquifer is unconfined, isotropic and homogeneous. This assumption was made to simplify calculations and to allow the maximum interpretation of data. The description of the aquifer stratigraphy presented above indicates that this simplifying assumption does not properly represent the Missoula Aquifer. However, there is currently insufficient information available to analyze the aquifer using a more accurate model. Even considering the heterogeneities of the Missoula Aquifer, aquifer testing and interpretation is believed to result in generally conservative estimates of aquifer properties.

Four 50 gallon samples of aquifer material from Unit One were evaluated by Clark (1986) to determine values for specific yield, porosity and hydraulic conductivity. The hydraulic conductivities of the samples were also estimated from the sieve analysis data using techniques developed by Slichter and Terzaghi described in Fraser (1938). Aquifer properties derived from these

methods were considered estimates applicable to Unit One and, assuming a similar depositional environment, Unit Three.

Aquifer properties for Units Two and Three were determined by analysis of aquifer testing data. In the first method used, drawdown and pumping information recorded on driller's reports were analyzed to calculate transmissivity using a computer program (PTRAN) (Appendix 3B). Clark (1986) describes the assumptions used to develop the program. Several problems were encountered using this technique. First, domestic wells posed a challenge as they are typically finished as open ended casings and do not penetrate the full aquifer thickness. In an attempt to use the maximum available data, an aquifer penetration value of one foot was used for open ended wells. For most domestic wells, aquifer thickness was interpreted as the length of continuous saturated coarse sand and gravel extending upwards from the bottom of the well casing. For large water company wells, the saturated thickness was assumed to be the thickness of Unit Three or, if Unit Two was absent, the thickness of Unit Three plus the saturated portion of Unit One. Second, inaccuracies in measurements by drillers directly affect calculated transmissivity values. For instance, pumping times are often rounded to the nearest hour, drawdown in wells pumped by airlifting is difficult to determine and variations in discharge may go undetected. These problems are more common for analysis of data from smaller diameter wells drilled by rotary rigs than with the few dozen larger diameter wells drilled by cable tool.

Aquifer testing on well MWC34 was the second method used to calculate transmissivity for Unit Three (Plate 1). The tests also provided values of horizontal and vertical hydraulic conductivity and specific yield. Clark (1986) describes the details of the aquifer testing.

RESULTS OF AQUIFER PARAMETER DETERMINATION

Results of aquifer parameter determination from the combined laboratory and field tests and from analyses of driller's reports are summarized in this section. Results are organized by hydraulic units and summarized in Table 3.3.

TABLE 3.3
Estimates of Aquifer Properties

Property	Unit One	Unit Two	Unit Three
Porosity	0.20	---	0.20
Specific Yield	0.12	---	0.10
Thickness (ft)	10-30	40	50-150
Hydraulic Conductivity (gpd/ft ²)	10,300	200	10,300- 25,500
Vertical Hydraulic Conductivity (gpd/ft ²)	---	---	970-2,100
Transmissivity (gpd/ft)	103,000- 310,000	8,000	750,000- 1,710,000

Laboratory determinations of hydrologic properties of Unit One revealed average values of 0.20 for porosity, 0.12 for specific yield, 0.08 for specific retention, and 10,370 gpd/ft² for hydraulic conductivity.

The sieve analyses of Unit One samples yielded hydraulic conductivity values which vary over 2 orders of magnitude (Clark, 1986). The large differences in calculated values are caused by the four to eight fold variation in the mean and effective grain diameters of samples. An average hydraulic conductivity value for the four samples computed with both methods is 2,953,710 gpd/ft².

Grimestad (1977) reported a hydraulic conductivity value of 10,250 gpd/ft² and a specific yield of 0.20 to 0.35 for the surficial gravel which corresponds to Unit One.

Morgan (1986) estimated hydraulic properties of Unit Two from driller's specific capacity data from a small number of wells finished in what he interpreted as the finer middle unit. Average specific capacity was 7 gpm/ft. Using estimating techniques described by Driscoll (1986) which convert specific capacity to transmissivity, Morgan calculated a representative transmissivity for the unit of about 10,500 gpd/ft. Based on an average thickness of 40 ft, the hydraulic conductivity is approximately 260 gpd/ft². Grimestad (1977) reported a hydraulic conductivity of 150 gpd/ft² for his middle unit.

Unit Three hydraulic properties were obtained from analysis of drillers' reports and aquifer tests. Estimates by Clark (1986) of transmissivity generated from specific capacity data using the computer program PTRAN are presented in Appendix 3C. Transmissivity values computed from specific capacity data range from 52 to 4,149,000 gpd/ft for domestic wells and average 365,600 gpd/ft. Values for municipal wells range from 48,000 to 9,752,000 gpd/ft and average 1,710,000 gpd/ft. An average value of transmissivity for both municipal and domestic wells is 750,000 gpd/ft. Hydraulic conductivity values for municipal wells range from 520 to 113,400 gpd/ft² and average 25,500 gpd/ft². Values for domestic wells range from 1 to 27,700 gpd/ft² and average 4,100 gpd/ft². The average value for both municipal and domestic wells is 10,300 gpd/ft².

Morgan (1986) reported specific capacity data for over 50 wells completed in Unit Three and found an average specific capacity value of 240 gpm/ft for these wells. Estimation of hydraulic conductivity and transmissivity from these data using Driscoll's (1986) method yields a range of hydraulic conductivity values between 3,600 and 7,200 and a transmissivity of 360,000 gpd/ft (Driscoll, 1986).

Results of the two aquifer tests conducted by Clark (1986) provide transmissivity values for Unit Three which vary considerably and range from 606,000 to 5,856,000 gpd/ft (Table 3.3). Specific yield values ranged from 0.03 to 0.07. Depending on the assumptions used, horizontal hydraulic conductivity ranged from 6,400 gpd/ft² to 62,300 gpd/ft². Values of vertical hydraulic conductivity ranged from 970 gpd/ft² to 2,100 gpd/ft². The tests

were not conducted under ideal conditions as Mountain Water Company's pumping schedule for MWC34 could not be altered to benefit the tests.

The distribution of hydraulic conductivity and transmissivity values calculated from specific capacity data by Clark (1986), Meyer (1985) and Pottinger (1988) are presented in Figures 3.8 and 3.9. One pattern emerges in the western portion of the study area where values of transmissivity and hydraulic conductivity are lower (Clark, 1986, and Meyer, 1985). However, the work (Meyer, 1985) which generated these lower values is poorly documented. The distribution of hydraulic conductivity and transmissivity data in the Missoula Aquifer also appears to reflect an area of higher hydraulic conductivity and transmissivity values near the mouth of Hellgate Canyon and adjacent area south and southwest of the river.

Values for aquifer properties of Unit Three generated for this report are similar to values reported by previous workers. Using data from specific capacity tests, McMurtrey and others (1965) determined transmissivity values which varied from 17,800 to 1,000,000 gpd/ft. From an aquifer test in the north central part of the study area, these workers also calculated a transmissivity value of 620,000 gpd/ft. An aquifer test by Geldon (1979) provided a transmissivity value of 699,927 gpd/ft. Hydrometrics (1984) attempted an aquifer test on MWC34, the same well tested by Clark (1986), and concluded that transmissivity ranged from 250,000 to 1,000,000 gpd/ft, in good agreement with Clark (1986). From 19 aquifer tests, Geldon (1979) reports an average hydraulic conductivity value of 5,090 gpd/ft². In the same test series, he determined specific capacity values ranging from 3 to 3,000 gpm/ft.

Grimestad (1977) reported a hydraulic conductivity range of 3,400 to 16,660 gpd/ft² for Unit Three in the central valley area. McMurtrey and others (1965) reported that the transmissivity for two wells producing water from the same unit ranges from 77,000 to 125,000 gpd/ft.

McMurtrey and others (1965) assumed a porosity value of 0.40 and a specific yield of 0.10. From aquifer tests Geldon (1979) found time-dependent specific yield values which ranged from 0.11 to 0.35.

SUMMARY OF HYDROLOGIC PROPERTIES

The vertical and horizontal heterogeneities in stratigraphy throughout the aquifer contribute to the wide range in hydrologic values. It is difficult to generalize about these properties. The most reliable values for each property have been selected and are summarized in Table 3.3. The rationale for selecting each value is explained below. Generally, it is believed that aquifer properties derived from aquifer tests, permeameter experiments and driller's log analyses are most accurate. Hydraulic conductivity values calculated from sieve analyses were considered too high and were rejected because the techniques are intended for sand and not coarse sand and gravel.

The hydraulic properties assigned to Unit One are based on the permeameter testing data presented by Clark (1986) and thickness data reported by Morgan (1986). Transmissivity values were obtained by multiplication of

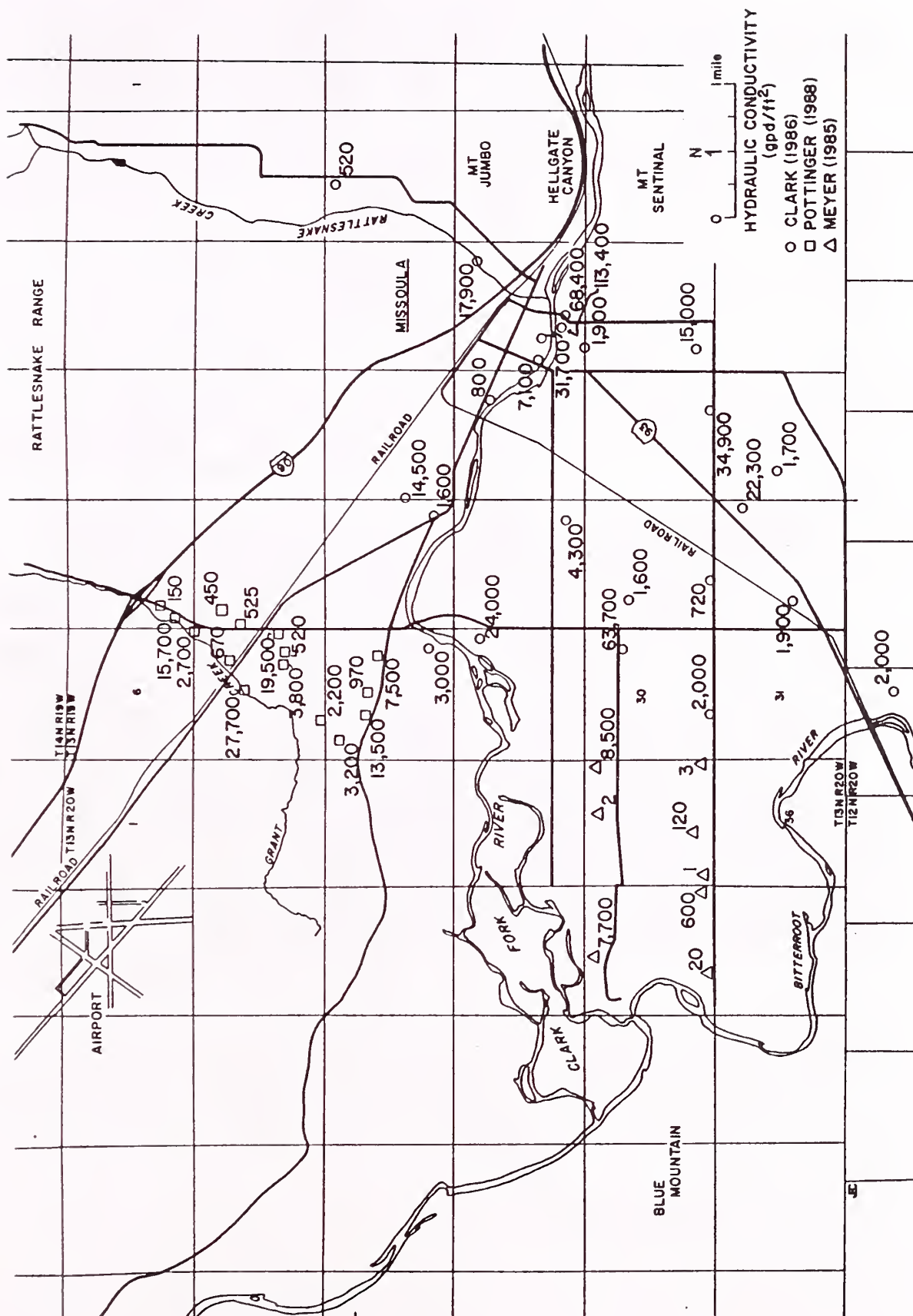


Figure 3.8: Distribution of hydraulic conductivity calculated from specific capacity data.

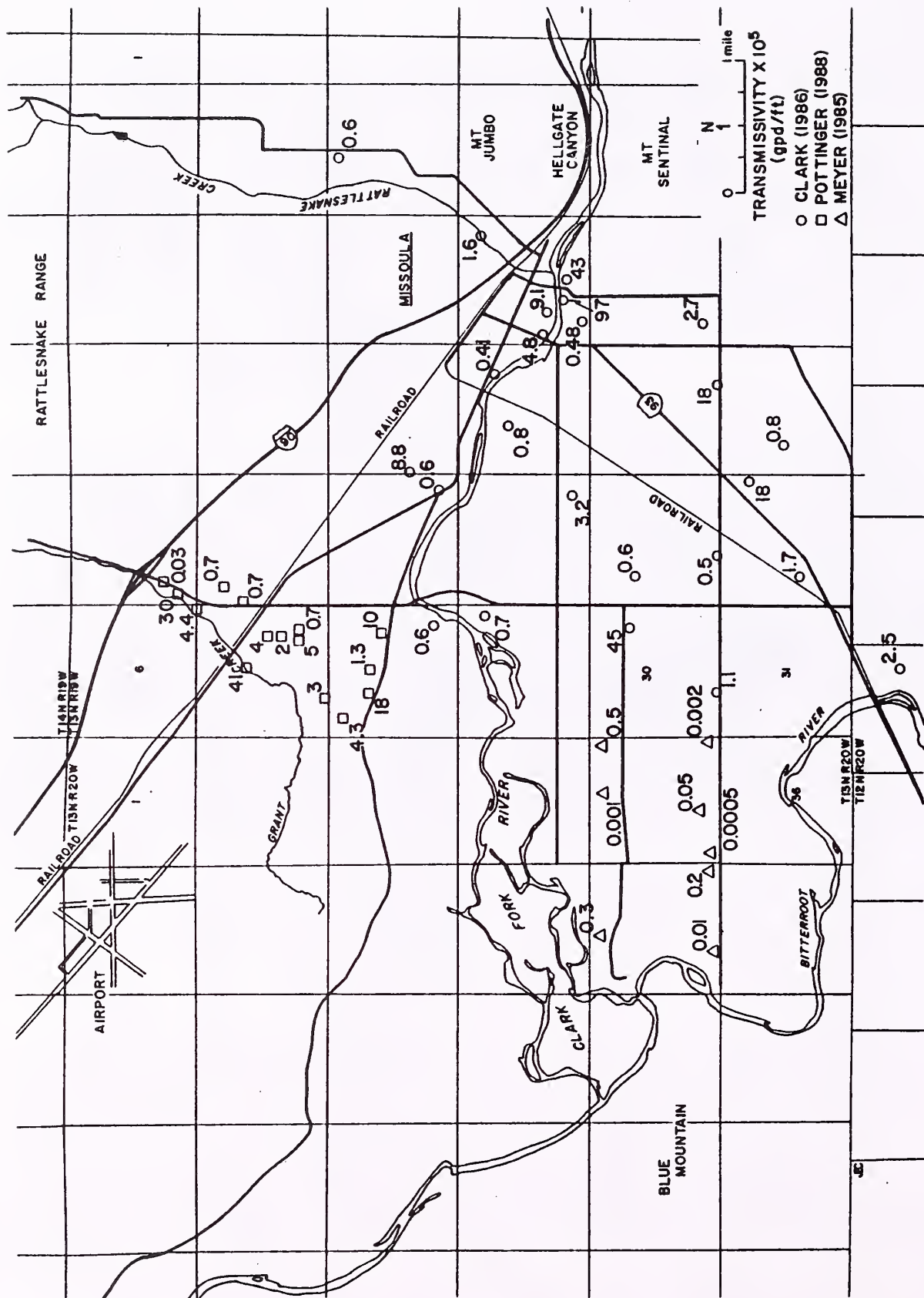


Figure 3.9: Distribution of transmissivity calculated from specific capacity data.

hydraulic conductivity by thickness. For Unit Two specific capacity and saturated thickness data came from Morgan (1986). Hydraulic conductivity estimates were obtained by averaging interpretations of Morgan's data for Unit Two and Grimestad's (1977) value for his intermediate unit.

In Unit Three porosity was derived from the permeameter work by Clark (1986). Specific yield was estimated from the permeameter data, from aquifer tests conducted by Clark (1986), and from McMurtrey and others (1965). Aquifer thickness is presented as a range of values based generally on work by Clark (1986), Morgan (1986) and Pottinger (1988). Hydraulic conductivity is presented as a range. The low value corresponds to permeameter results (Clark, 1986) and the higher value represents an average calculated from Mountain Water Company well specific capacity data. Vertical hydraulic conductivity values come from Clark's (1986) aquifer tests. The selected transmissivity values were calculated from specific capacity data. The lower value is the average transmissivity computed from all specific capacity data. The higher value is the average from specific capacity data from just Mountain Water Company wells. This range of transmissivity values is supported by Clark's (1986) aquifer tests.

Single of single values for transmissivity and hydraulic conductivity for Unit Three were selected based on data obtained from wells which were drilled with cable tool methods, had perforated aquifer intervals with known aquifer thickness, and whose pumping tests were at least four hours long. Transmissivity values from municipal wells (MWC) best fit these criteria and average 1,710,000 gpd/ft. Hydraulic conductivity values average 25,500 gpd/ft².

The values given in Table 3.3 provide a general description of the Missoula Aquifer and indicate that the aquifer is highly conductive. Unit Two appears to be significantly lower in transmissive ability than Units One or Three, although the actual range and spacial variation in Unit Two's hydraulic properties throughout the study area are not well understood. Hydraulic conductivity and transmissivity values appear extremely high for Unit Three. Operation of large production wells in this unit have small drawdowns, which support these high values. As an example, well MWC34 pumps at 7,000 gpm and typically has less than eight feet of drawdown at the well. MWC23 and MWC35 are located away from the river and yield 250 and 2,500 gpm with one and six feet of drawdown, respectively (Plate 1).

In an attempt to characterize the aquifer with just a few numbers, the hydrologic properties were calculated for a hypothetical composite aquifer composed of 10 ft of Unit One, 20 ft of Unit Two and 60 ft of Unit Three. The weighted average value for hydraulic conductivity is 18,200 gpd/ft² and 1,152,000 gpd/ft for transmissivity. Single values for porosity and specific yield are 0.20 and 0.12, respectively.

CHAPTER 4

WATER TABLE FLUCTUATIONS

This chapter addresses three objectives: 1) describe the network of observation wells used to measure changes in water table elevation and aquifer storage during the study; 2) present and discuss the observed data; and 3) evaluate these water level changes in a historical context.

MONITORING WELL NETWORK

The well monitoring network developed during this study is composed of several different groups of wells. In the summer of 1985 the first 31 domestic wells were chosen and given the MV label. Criteria for selection of these wells included access, potential for long term monitoring, availability of a driller's log, and location in the flow system. Twenty-nine of these wells were monitored monthly until summer 1987. Two wells were monitored monthly until summer 1986. Well locations are presented on Plate 1 and in Figure 4.1.

Additional water level data for the valley were obtained from a 48 well network (labeled P) used by Pottinger (1988) during a detailed investigation in the vicinity of Interstate 90 and Grant Creek (Plate 1) and 24 Mountain Water Company (MWC) wells (Figure 4.1). Pottinger (1988) measured water levels monthly from summer 1985 to summer 1986. Water level records for most MWC wells begin in the mid 1970's. Typically, measurements were recorded one to three times each year until 1984 when monthly water level records were kept. Monthly measurements were made at all MWC wells throughout the duration of this project.

The only well for which there is a water level record longer than the MWC wells is MV31 (also MWC7) located in the parking lot of Montana Power Company's Missoula office. This well was monitored monthly by the USGS from September 1958 until December 1966; quarterly by the USGS until July 1981, sporadically by the MWC and USGS from 1981 to 1984, and monthly by this project starting in summer 1985. An electrical transducer system capable of recording daily water level fluctuations was installed in July, 1986.

By December 1985, seven additional monitoring wells were constructed as part of this project (MV34 to MV40) and were monitored monthly (Figure 4.2). Two additional wells (MV41 and MV42) were constructed in summer 1986 as part of the storm drain study (Wogsland, 1988). These nine wells were drilled with a direct air rotary drilling rig equipped with a drill-through casing driver. Ten inch surface casing was set to 20 ft below land surface and six inch steel casing was advanced to approximately 10 ft below the water table. Drill cuttings were collected at five foot intervals. The wells were perforated with a down-hole perforator over a 10 to 20 ft interval approximately centered at the water table. Five rounds of perforations were cut. Each perforation was 0.10 ft long and 0.01 ft wide. The wells were grouted with a cement slurry which was poured in from the top of the ten inch surface casing as this ten inch casing was removed. To complete construction, a steel instrument

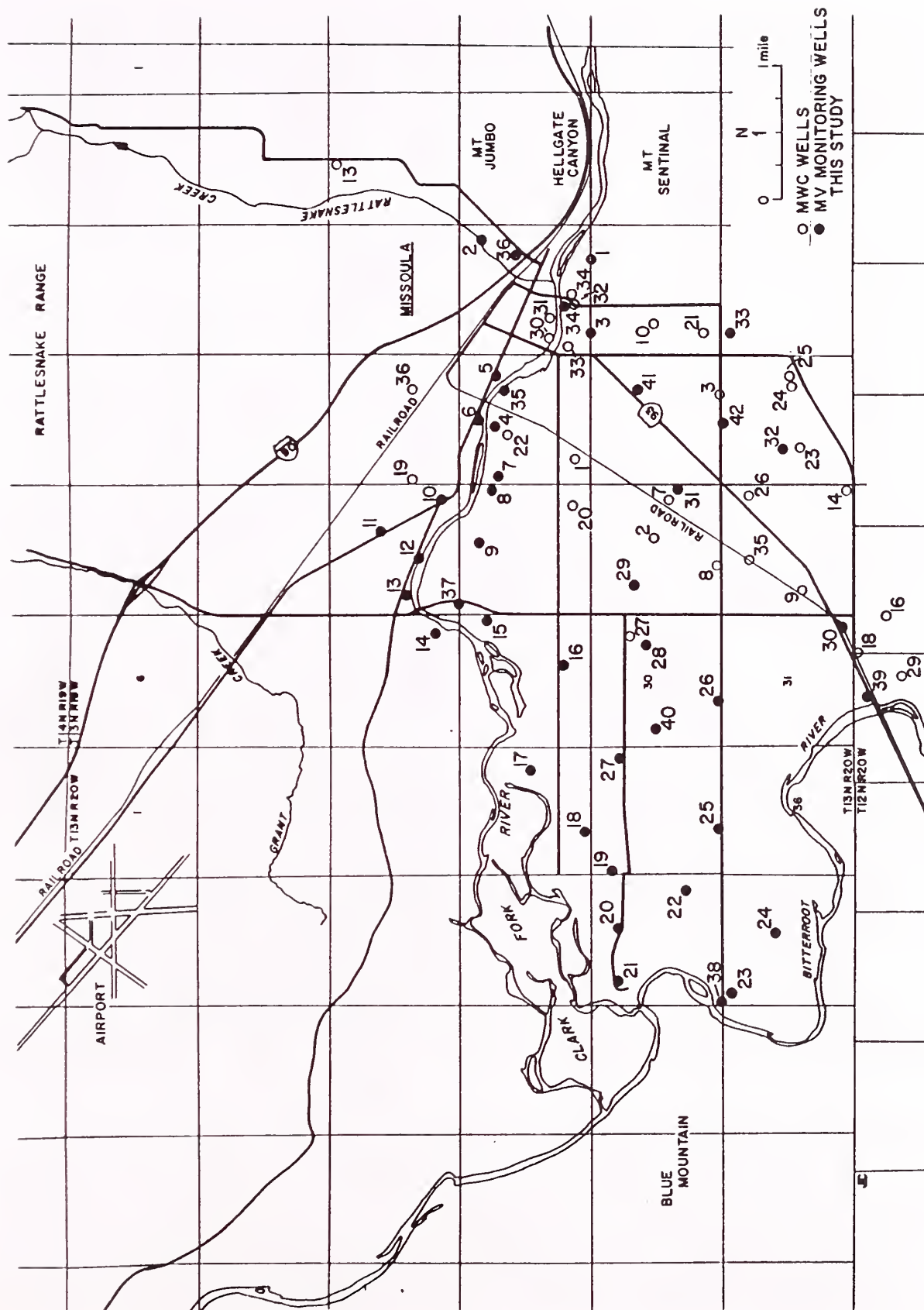


Figure 4.1: Location of project monitoring network wells and Mountain Water Company wells.

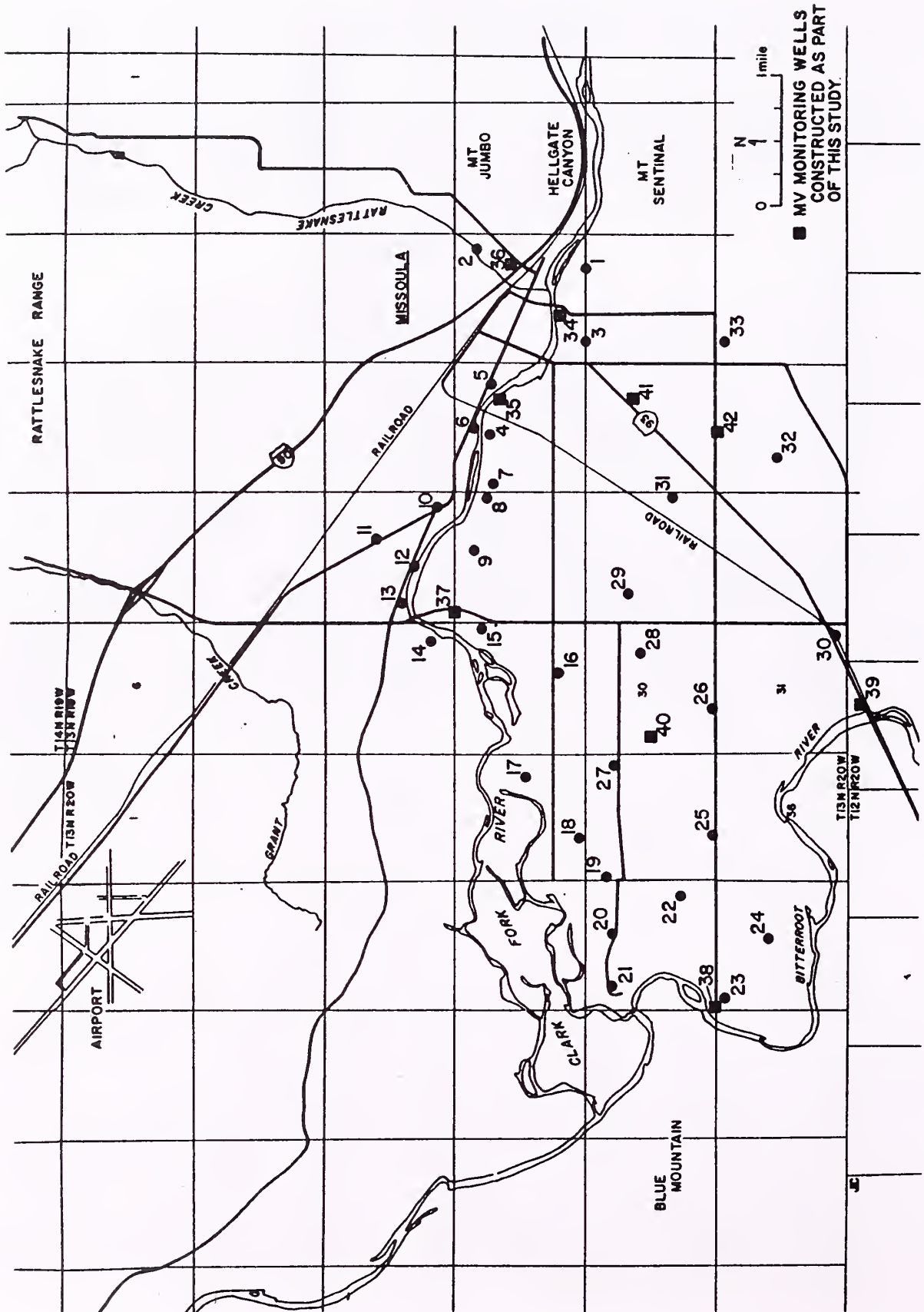


Figure 4.2: Location of monitoring wells constructed for this project.

shelter was welded to each well. The two wells completed in 1986 were finished with flush coupled PVC casing and 10 ft of 60 slot PVC well screen. The six inch steel casing was removed and the drill hole allowed to collapse around the screen. Two to three feet of bentonite pellets were installed above the screened interval. Twenty feet of six inch diameter steel casing was left in the top of the bore hole to protect the PVC casing and for attaching an instrument housing for a Stevens Type F continuous recorder. Well logs for each of the nine wells are presented in Appendix 4A.

All monthly water level data collected as part of this study were measured using steel tape. Water levels collected by Mountain Water Company were measured using either a tape or air line. Well inventory information for wells analyzed as part of this study is found in Appendix 3A. All water level data are tabulated in Appendix 4B.

Casing elevations in feet above mean sea level were surveyed by the Missoula County Engineers Office. Elevations are accurate to 0.01 ft.

One objective of this project was to construct a long term water level monitoring network for the Missoula Valley. Well MV31 and seven of the project constructed monitoring wells were equipped with electrical transducer systems in early summer 1986 (Figure 4.3). The use of transducers for long term monitoring of water level fluctuations is new. Systems installed in the Missoula Valley were modified from designs developed by the Northern Rocky Research group of the U. S. Forest Service (Prellwitz and Babbit, 1984).

RESULTS OF WATER LEVEL MONITORING

Data from the following wells illustrate the water level trends observed during the 1985 to 1987 study period:

1. MV34, MV35 and MV6, near the Clark Fork River;
2. MV31 and MV26, in the central portion of the area east of the Clark Fork River;
3. MV10, west of the Clark Fork River;
4. MV39 and MV20, near the Clark Fork and Bitterroot Rivers in the western portion of the study area;
5. MV2 and MV36, at the mouth of Rattlesnake Creek; and
6. P31, at the mouth of Grant Creek.

Figures 4.4 to 4.10 show hydrographs for each of these wells. Monthly water level data for all wells included in the monitoring well network are presented in Appendix 4B.

In addition to measurements of monthly water levels, daily water levels were measured at eight wells equipped with electrical transducers. The results of the transducer operation and actual monthly water levels are presented in Figures 4.11 to 4.14. Though battery problems affected data collection, transducer results are encouraging. The daily records generated from the transducer equipped wells support all trends observed from the monthly hydrograph data. Records for MV31 and MV36 show that transducer systems can be used to accurately record water level fluctuations (Figures

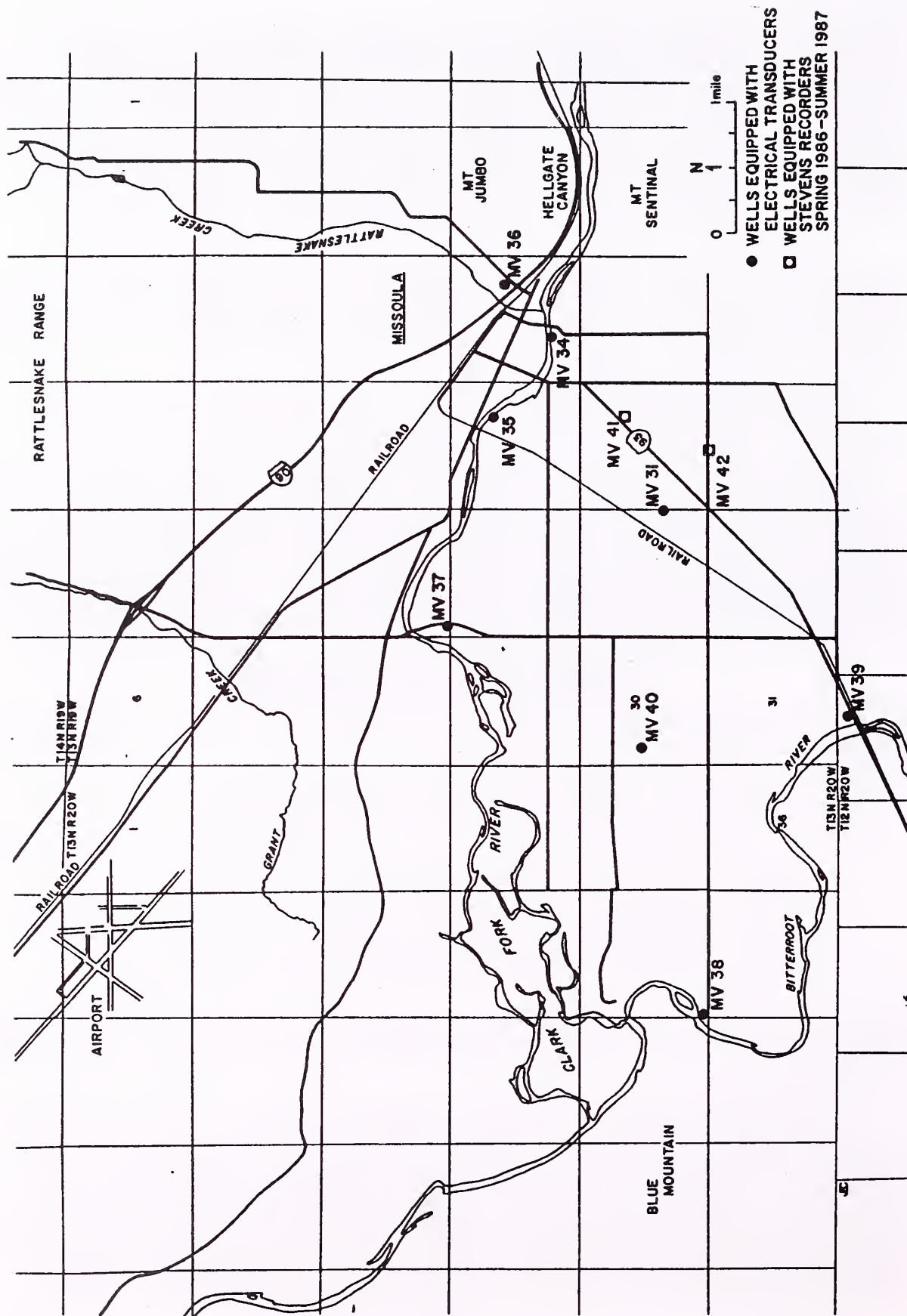
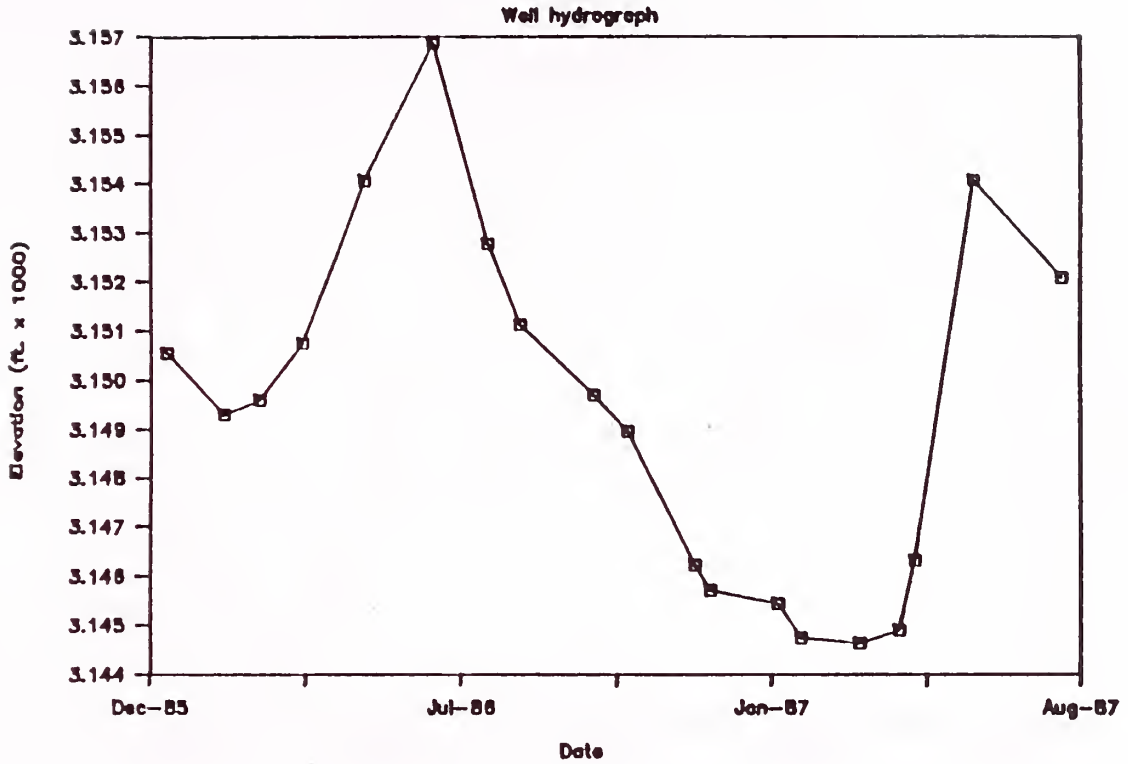


Figure 4.3: Location of wells equipped with water level recorders.

Madison St. Bridge — MV34



MV35

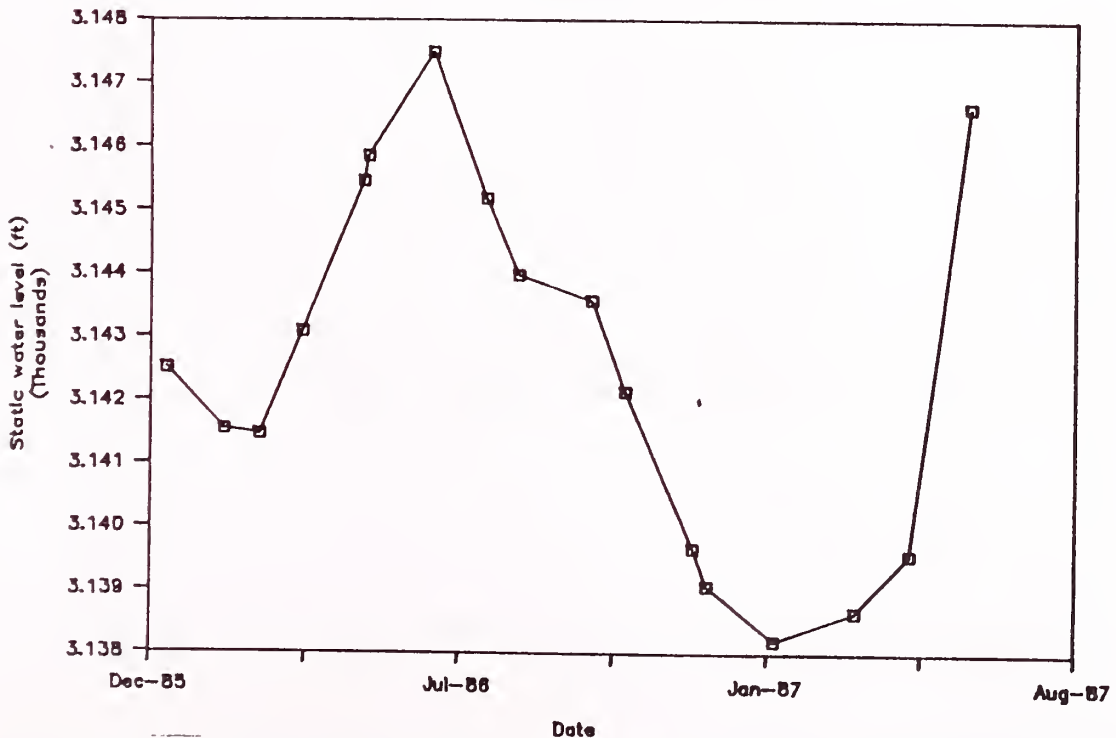


Figure 4.4: Hydrographs of data from wells MV34 (top) and MV35 (bottom).

MV06

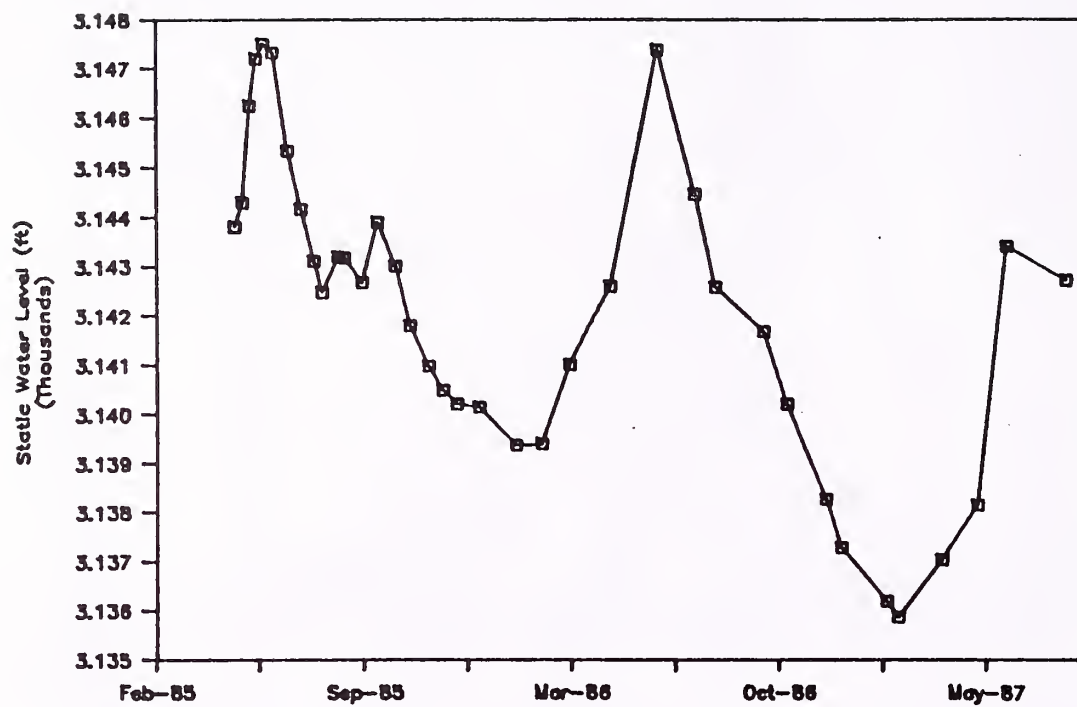
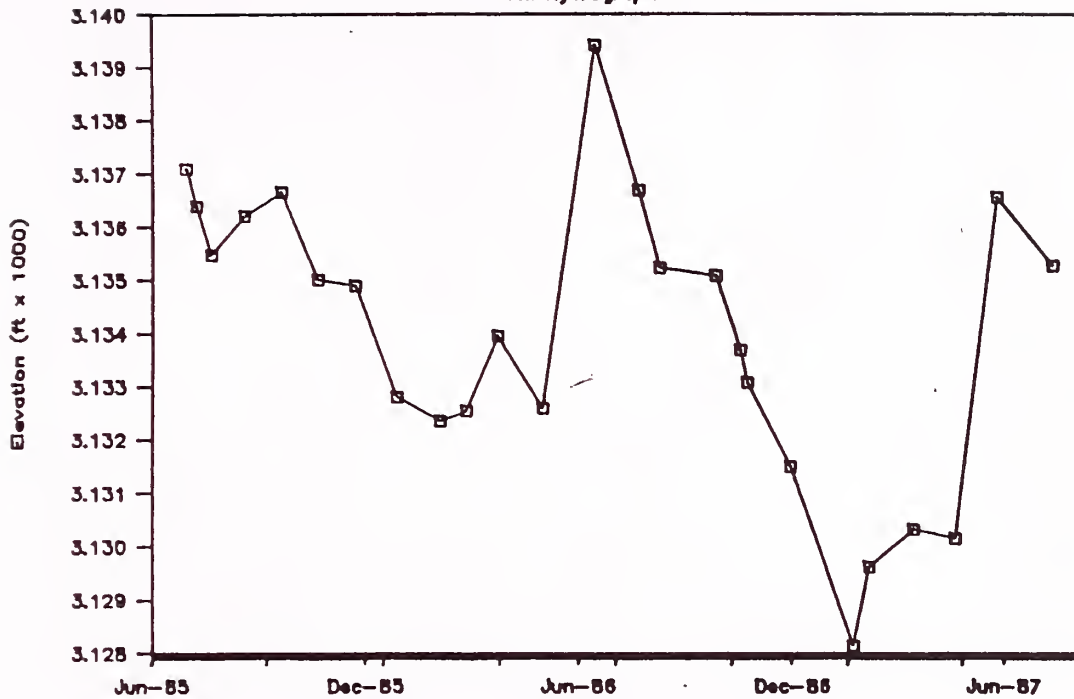


Figure 4.5: Hydrograph of data from well MV6.

MV31 — Montana Power

Well Hydrograph



MV26 — South Avenue

Well Hydrograph

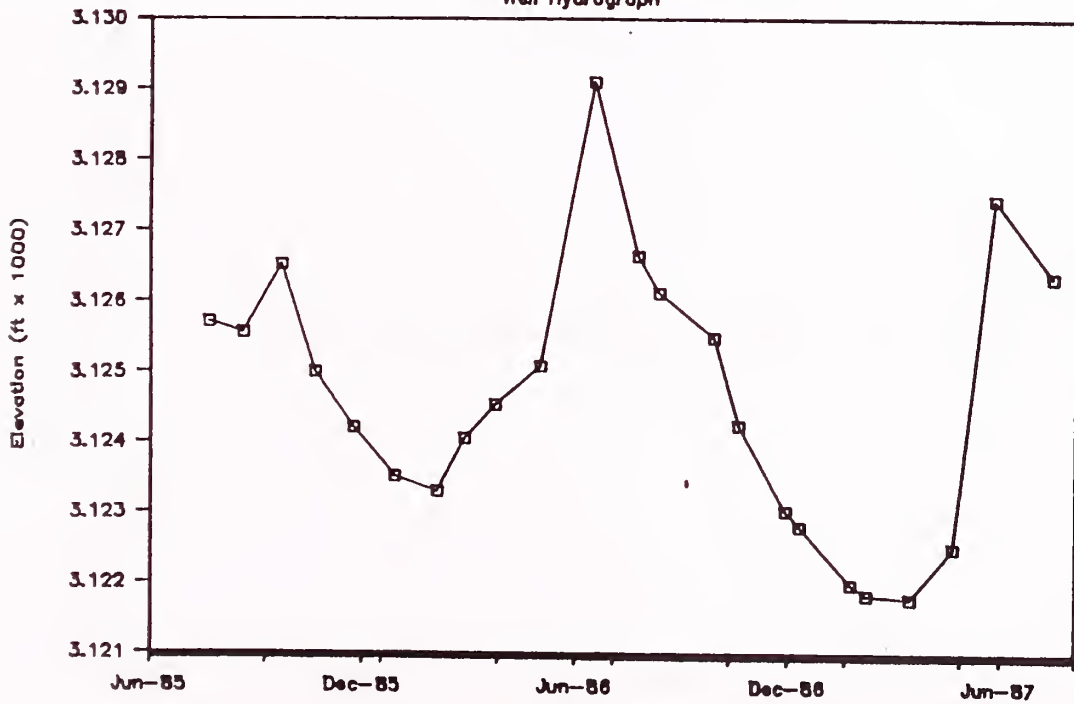


Figure 4.6: Hydrographs of data from wells MV31 (top) and MV26 (bottom).

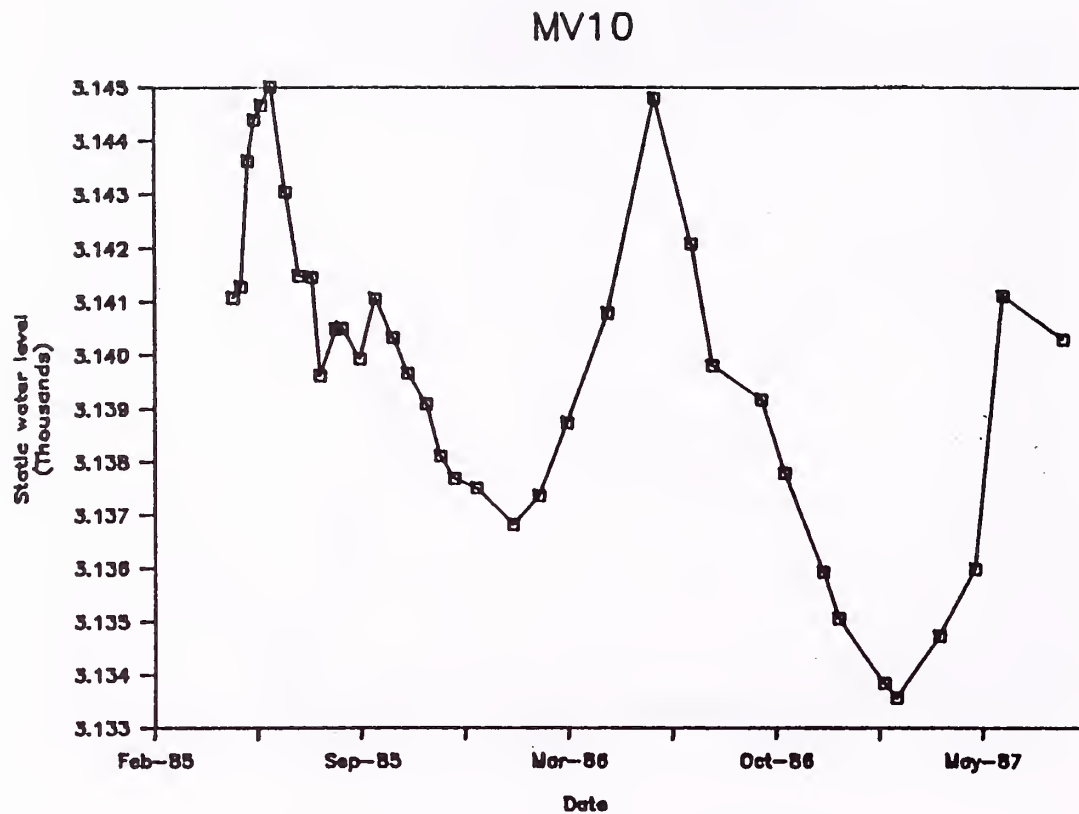
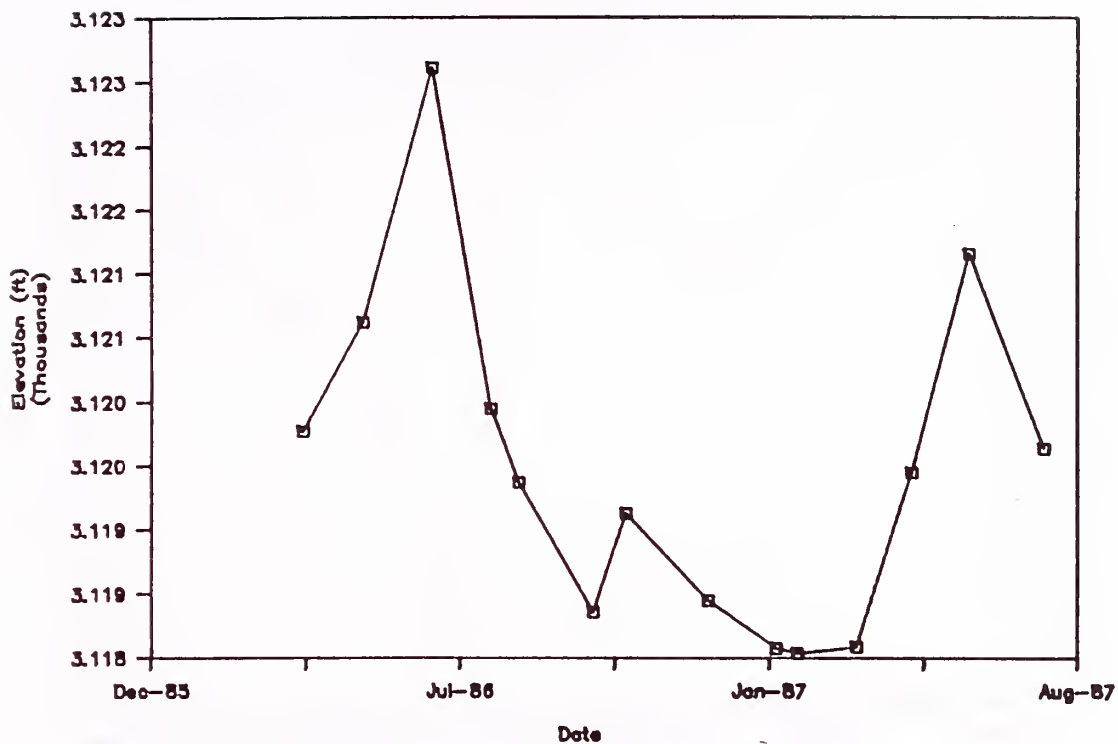


Figure 4.7: Hydrograph of data from well MV10.

Buckhouse – MV39



MV20, 4412 Spurgin Rd.

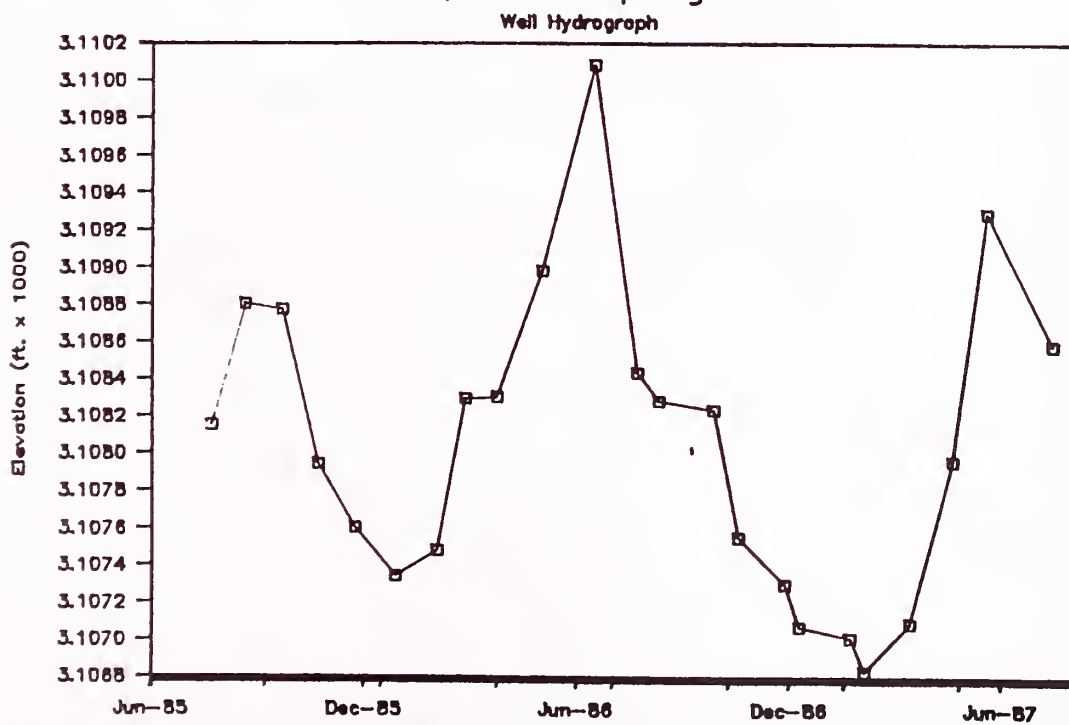
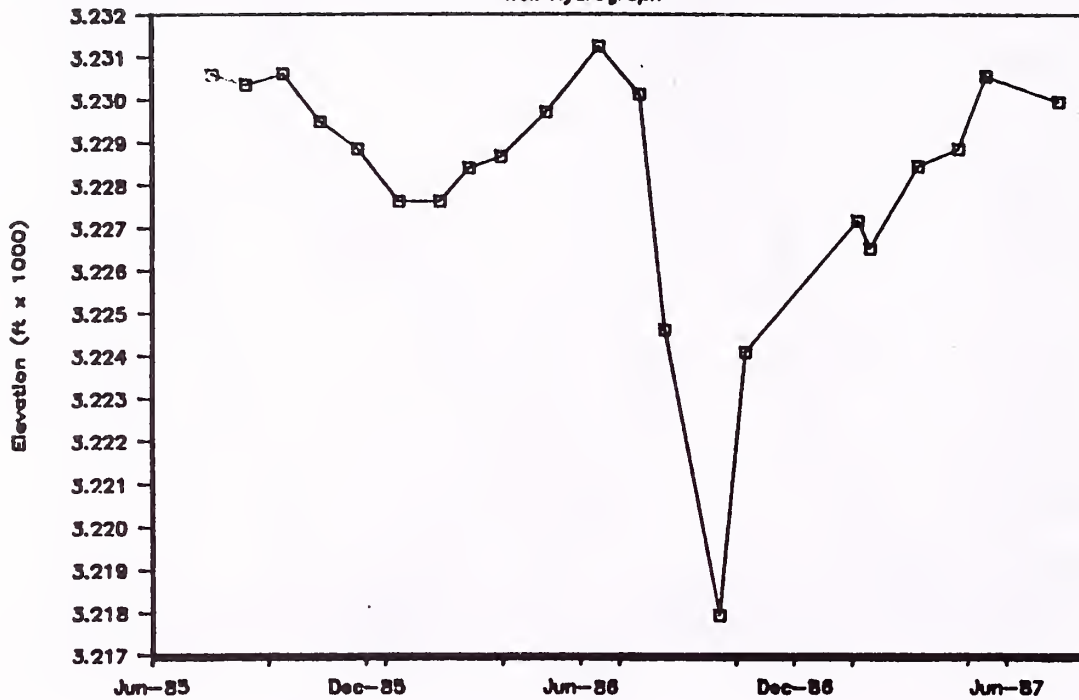


Figure 4.8: Hydrographs of data from wells MV39 (top) and MV20 (bottom).

MV2 - 1250 Monroe

Well Hydrograph



Greggory Park - MV36

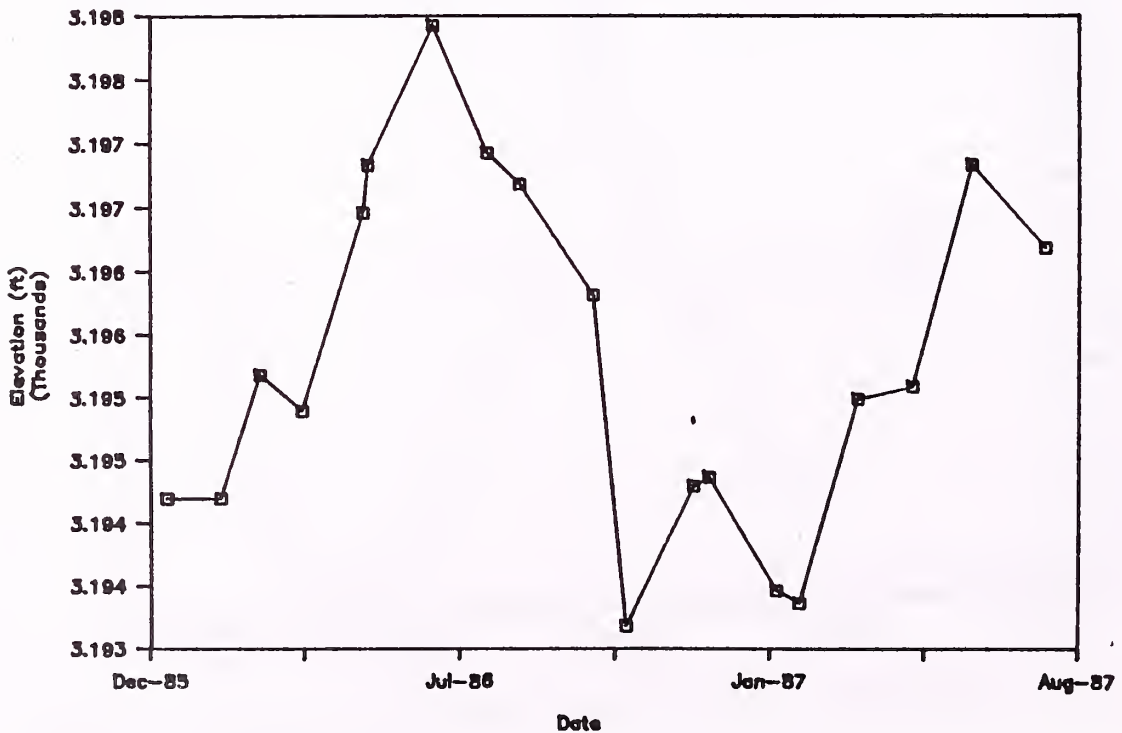


Figure 4.9 Hydrographs of data from wells MV2 (top) and MV36 (bottom).

Well #P31

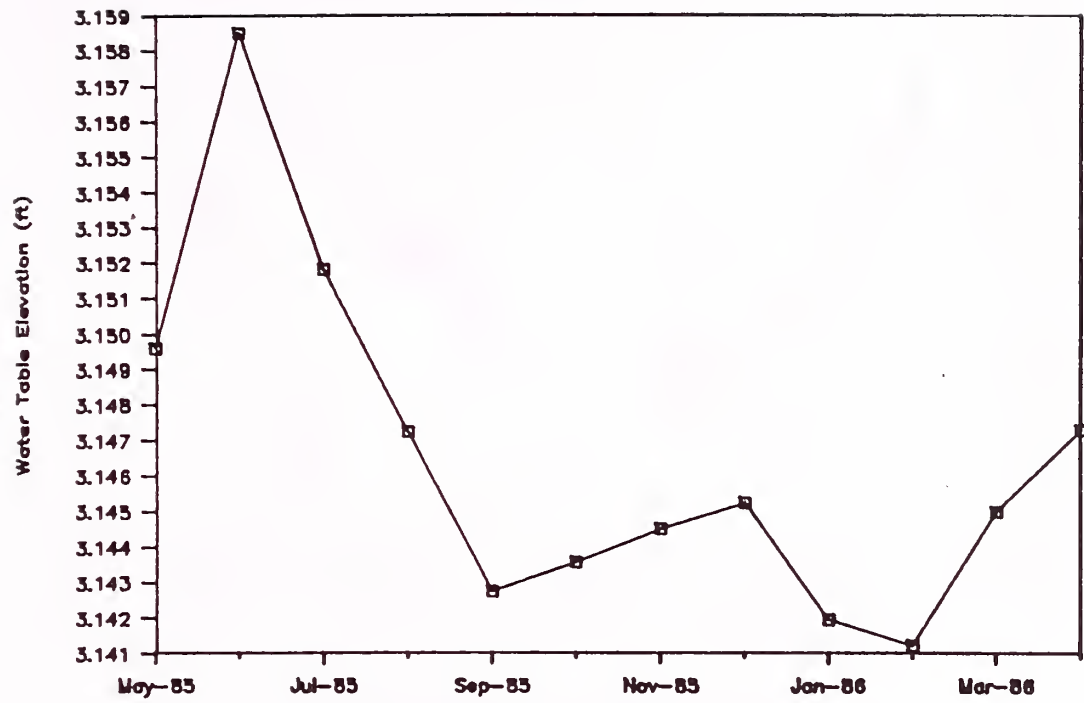
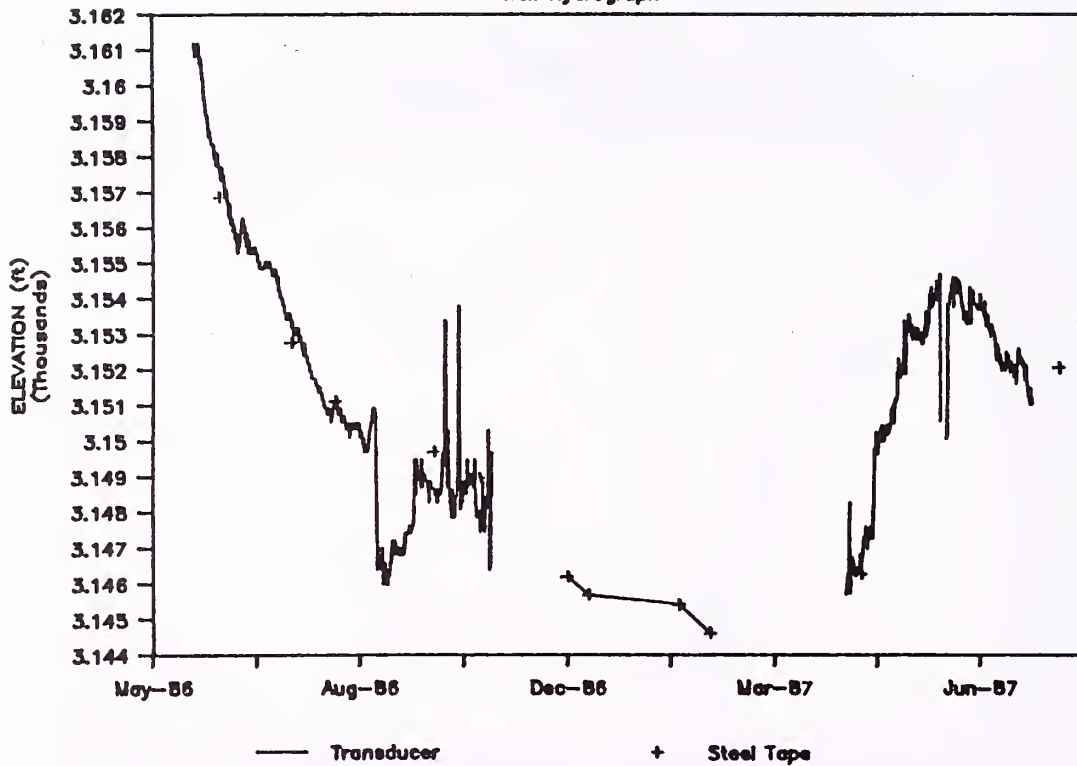


Figure 4.10 Hydrograph of data from well P31.

MADISON ST. BRIDGE — MV34

Well Hydrograph



MV35, McCormick Park

Well Hydrograph

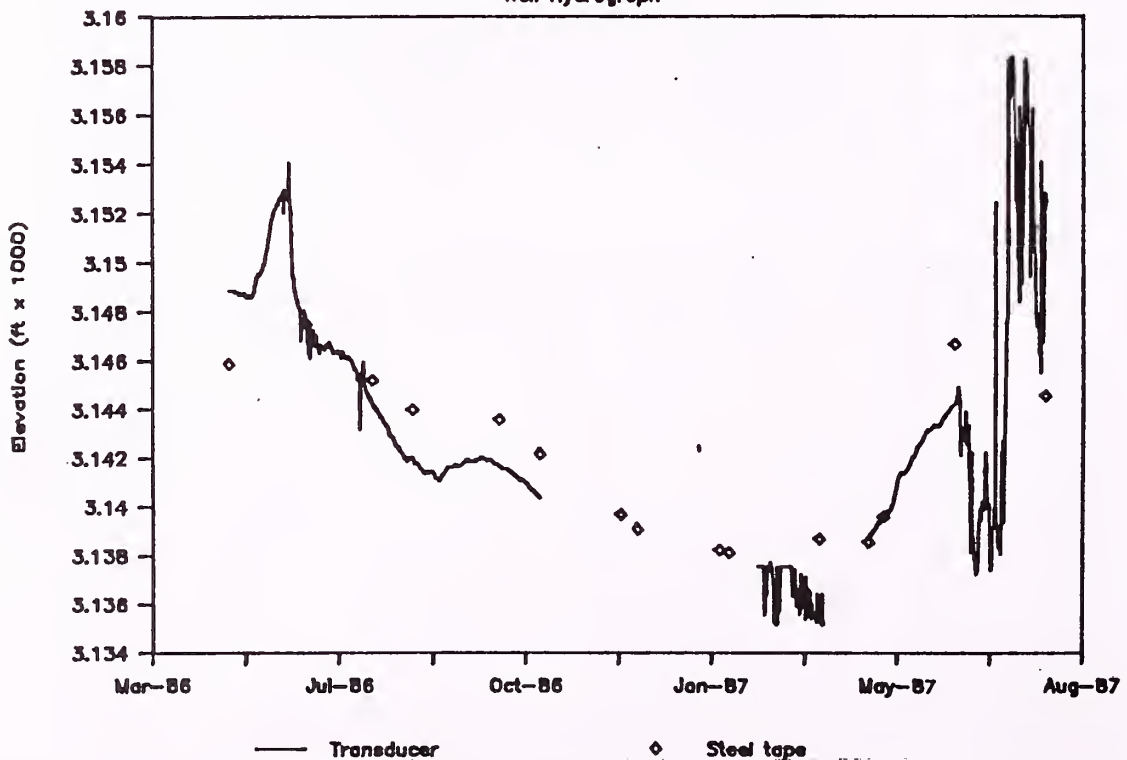
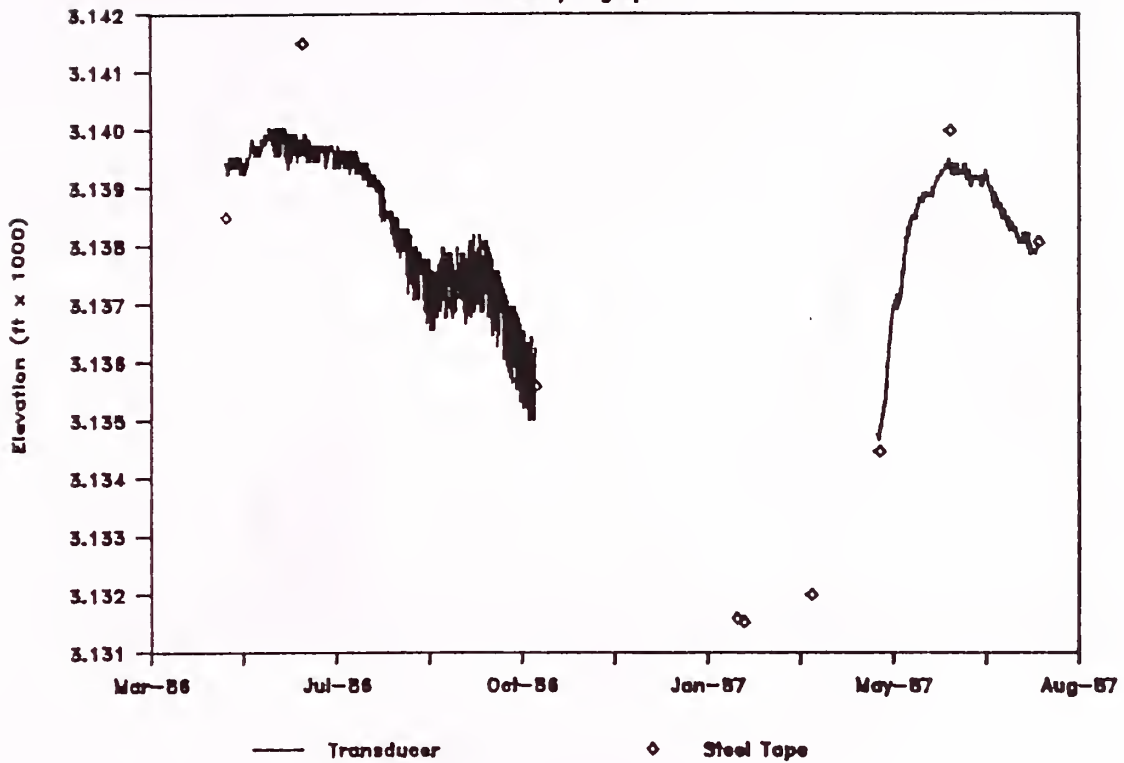


Figure 4.11: Hydrographs of transducer data from wells MV34 (top) and MV35 (bottom).

MV-37, Reserve Street

Well Hydrograph



MV31, Montana Power

Well Hydrograph

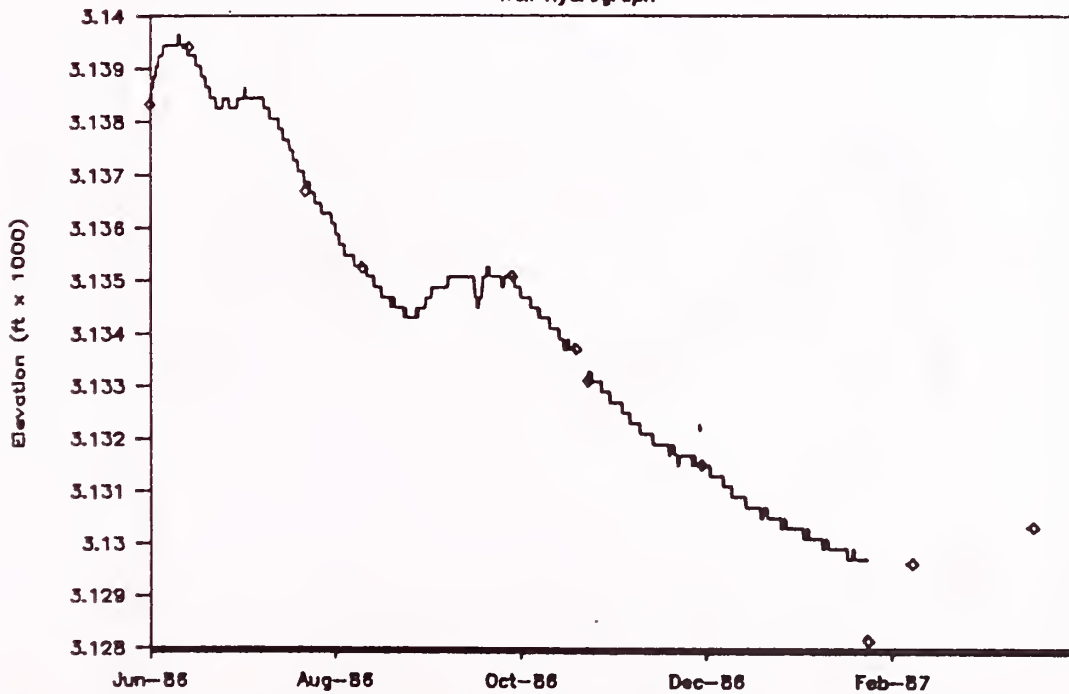
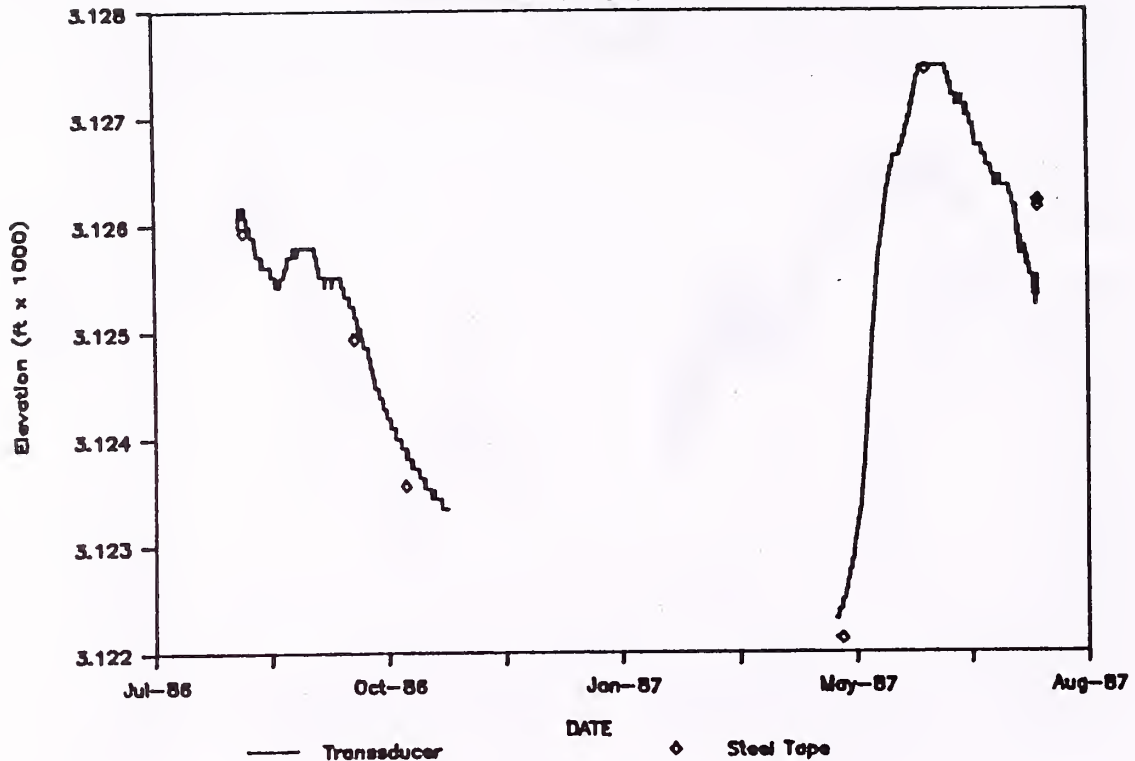


Figure 4.12: Hydrographs of transducer data from wells MV37 (top) and MV31 (bottom).

MV40, State Lands

Well Hydrograph



MV39, Buckhouse Bridge

Well Hydrograph

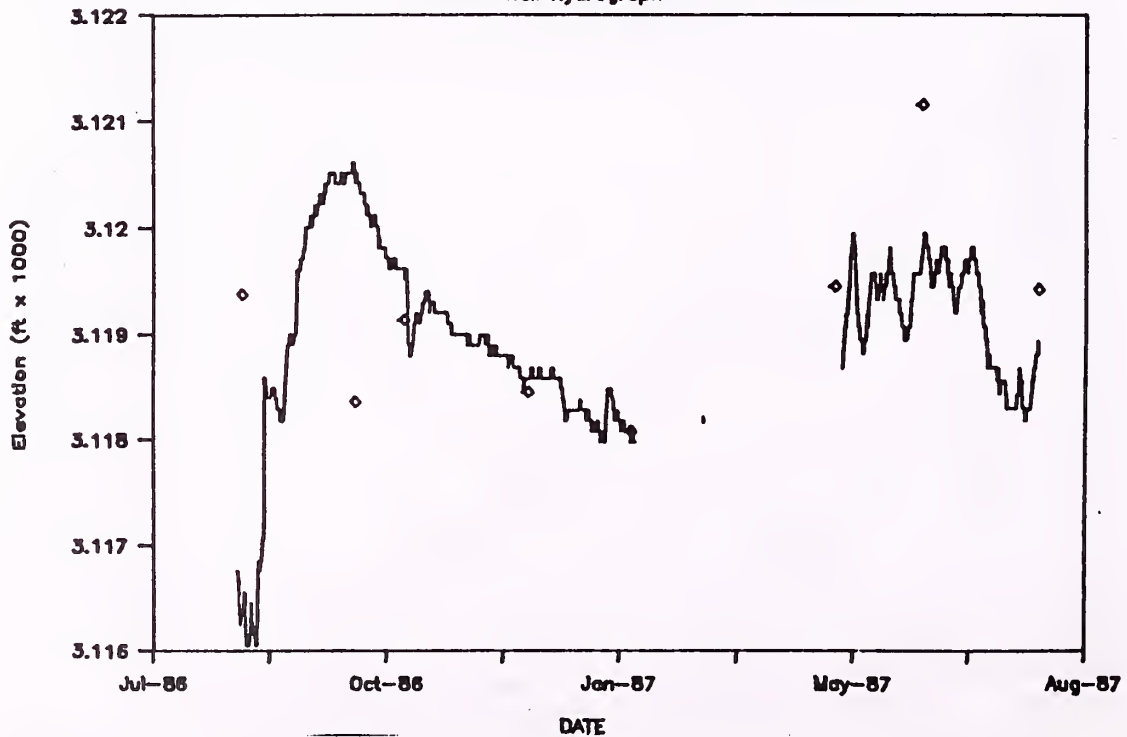
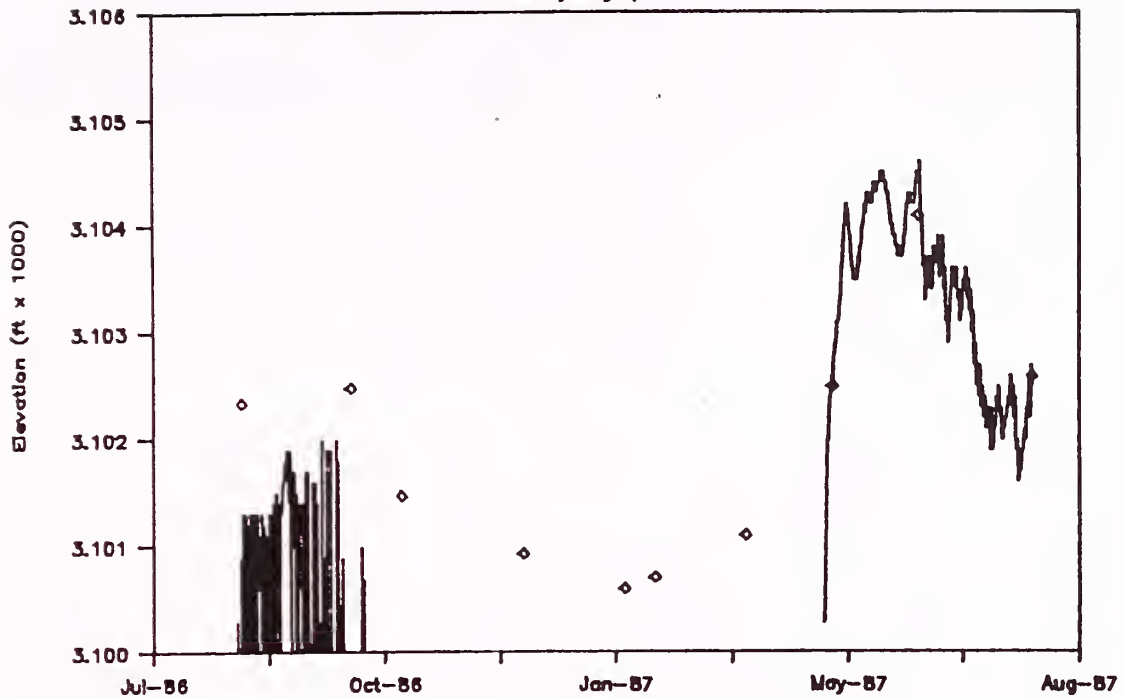


Figure 4.13: Hydrographs of transducer data from wells MV40 (top) and MV39 (bottom).

MV38, SOUTH AVENUE

Well Hydrograph



MV36, Gregory Park

Well Hydrograph

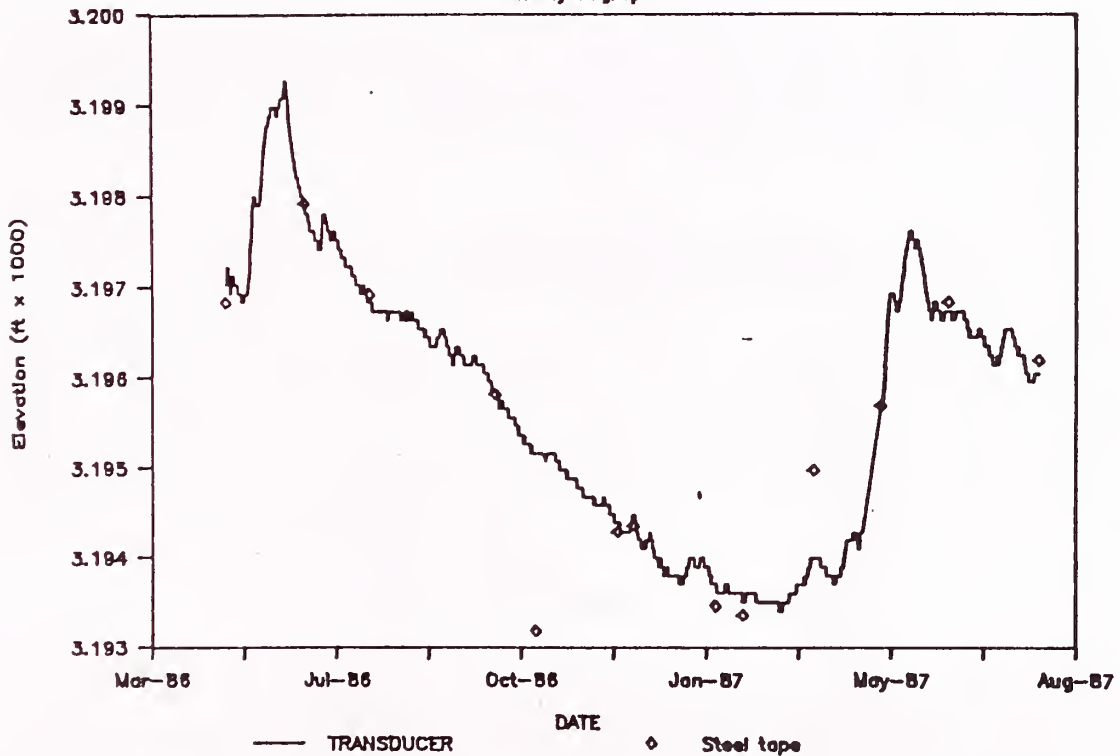


Figure 4.14: Hydrographs of transducer data from wells MV38 (top) and MV36 (bottom).

4.12 and 4.14). A number of the sites sustained battery failure in the winter. At other sites, minor operational problems were not recognized because of the field staff's lack of experience. This resulted in partial loss of daily records at the remaining stations. Transducers at MV40, MV34, MV35 and MV37 appeared to work well before power loss. Stations MV38 and MV39 required modification to obtain acceptable records.

Five significant trends are shown in Figures 4.4 to 4.14. The first is an annual water level rise which occurs between March and June and then a general decline until the following February or March. Table 4.1 summarizes the measured water level rises from the winter low to the spring peak. Transducer data were used in conjunction with monthly measurements to derive 1986 changes at MV34 and MV36. The spring rises were 6.5 to 12 ft in 1986 and 7.5 to 10 ft in 1987 at wells located immediately adjacent to the Clark Fork River (MV34, MV35 and MV6). MV31 is located further away from the Clark Fork River and showed spring water level rises of seven feet in 1986 and eight feet in 1987. MV26 increased about six feet during the spring of both years. The water table north of the Clark Fork River rose about eight feet at MV10 during both 1986 and 1987. Water levels at MV6 and MV10 were also collected prior to spring peak in 1985. These data show a decline of about eight feet from the peak to March. Spring water table rises at MV20 were about two feet each year and at MV39, two and one half to three feet. At the mouth of Rattlesnake Creek spring rises were at least four feet in 1986 and two feet in 1987 at MV36. Well MV2, located about a quarter of a mile up the creek, showed a three feet rise in 1986 and a 13 ft rise in 1987. This well has a peak water table position in the spring, and the lows occurred in late winter in 1986 and late fall in 1987. It is unclear what caused the drop and recovery of water levels in the fall of 1986. Possibly this water level reflects pumping of adjacent wells. Though only partial data are available to define the 1985 peak, the water table at P31, located at the mouth of Grant Creek, declined approximately 17 ft from the high measured in 1985.

TABLE 4.1
Net Water Table Rises from Winter to Spring Peak
(feet)

Well	1986	1987
MV34	12*	10
MV35	6.5	9
MV6	8	7.5
MV31	7	8.5
MV26	6	6
MV10	8.5	8
MV20	2	2
MV39	2.5	3
MV2	3	13
MV36	4	2

(*Transducer data used to define peak)

The second trend is defined by a decrease in the elevation of the spring peak water level at all wells in 1986 than in 1987. Minimum water table elevations were also lower in 1987 than 1986. Water table peaks at MV6 and MV10 were less than one foot higher in 1985 than 1986. The third trend is observed in seasonal water table fluctuations; the fluctuations decrease with increasing southward from the Clark Fork River. Fourth, wells located in the Missoula Aquifer near the mouths of Grant Creek and possibly Rattlesnake Creek show the largest annual fluctuations in water table elevation (Figures 4.9 and 4.10). Finally, water levels in wells located near the Bitterroot River are correlated with flow in the Bitterroot River and indicate that the ground water and river systems are linked. Maximum water level rises are on the order of three feet for wells located adjacent to river (Figure 4.8).

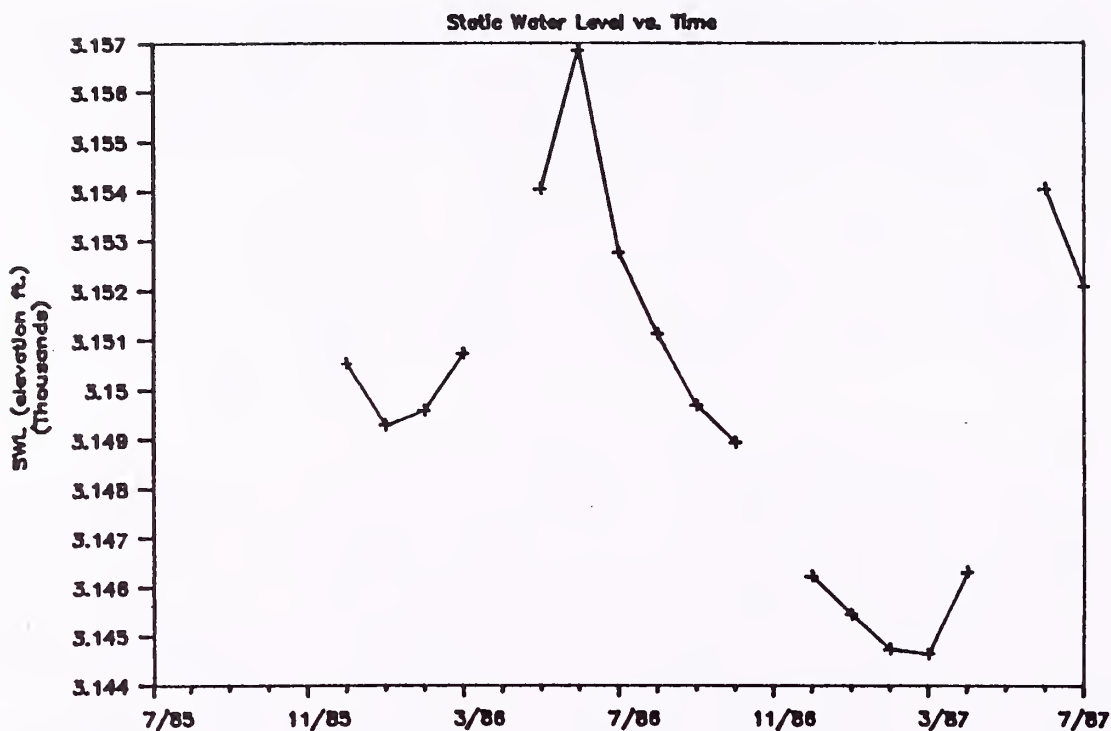
These trends probably reflect seasonal variation in recharge to the aquifer and increased withdrawal for public water supply. The maximum water table values observed between May and July correlate with the Clark Fork River stage as shown in Figures 4.15 and 4.16. Losses measured by Clark (1986) in stream discharge between the University Walking Bridge and the Reserve Street Bridge indicate that the river recharges the aquifer. Other evidence that recharge occurs from the Clark Fork River includes potentiometric maps which show that ground water flows to the north and south away from the river (Chapter 5), river stage elevations which are higher than the adjacent water table (Figures 4.15 and 4.16), and water level fluctuations at wells close to the river channel which are greater than those at wells farther from the river (Figure 4.17).

The water table declines naturally in response to seasonal reductions in Clark Fork River discharge and corresponding decreases in ground water recharge and to continued natural discharge from the system to the Bitterroot River and lower reaches of the Clark Fork River (Figure 4.18). The elevation of the water table at well MV39 is higher than the stage of the Bitterroot River, which indicates flow is maintained to the river from the aquifer. In addition to natural discharge from the system, ground water is withdrawn from individual, industrial and municipal wells. Although withdrawals vary seasonally, most total annual withdrawals have remained constant since the late 1970's. The one exception is the withdrawal of water from the aquifer by Mountain Water Company. Figure 4.19 presents the total monthly ground water withdrawal by the Mountain Water Company well network (Appendix 4C). Until 1983, just over 4 billion gallons of water were used each year, with the largest production occurring in the summer. After the abandonment of the Rattlesnake surface water supply in summer 1983, annual ground water withdrawal has been over 9.7 billion gallons. Peak monthly demands since 1983 have exceeded 1.2 billion gallons.

HISTORICAL WATER TABLE TRENDS

The water level data collected and compiled as part of this study represent the most extensive documentation of water table trends in the valley to date. However, in order to evaluate the long term trends in water table elevations, it is necessary to assess records collected over as many years as possible. The records for well MV31 (MWC7) provides water level data from 1958 to the present. This well is not pumped.

Madison St. Well – MV34



Clark Fork River – North Walking Bridge

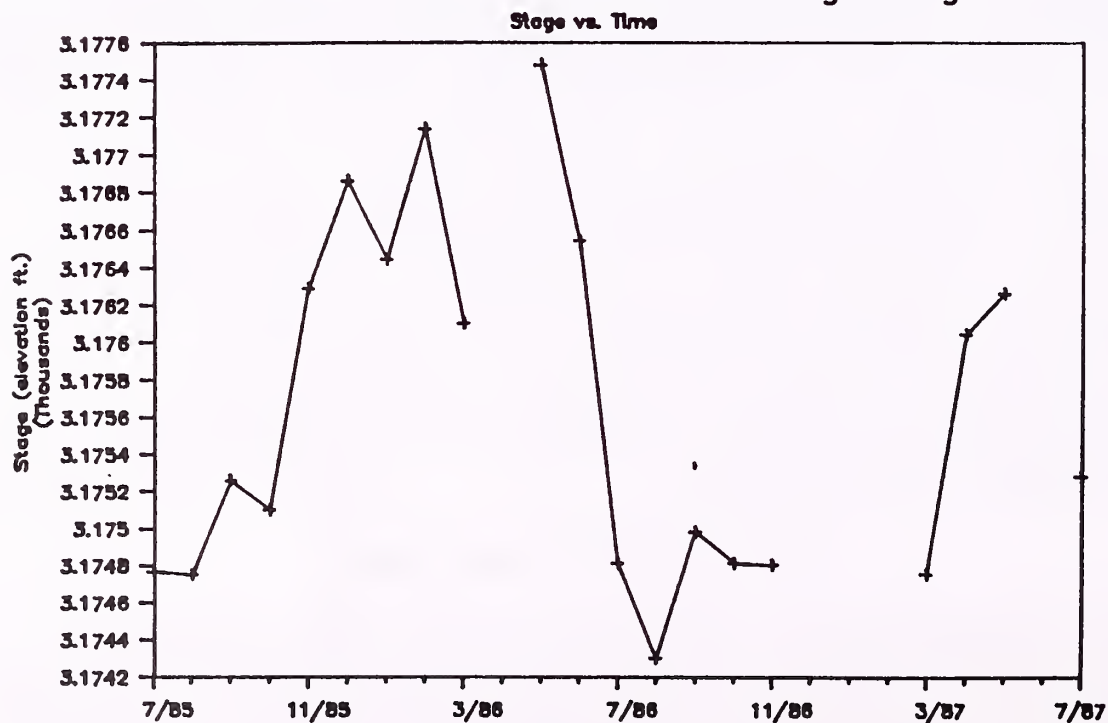


Figure 4.15: Hydrographs of data from well MV34 (top) and the Clark Fork River at the University Walking Bridge (bottom).

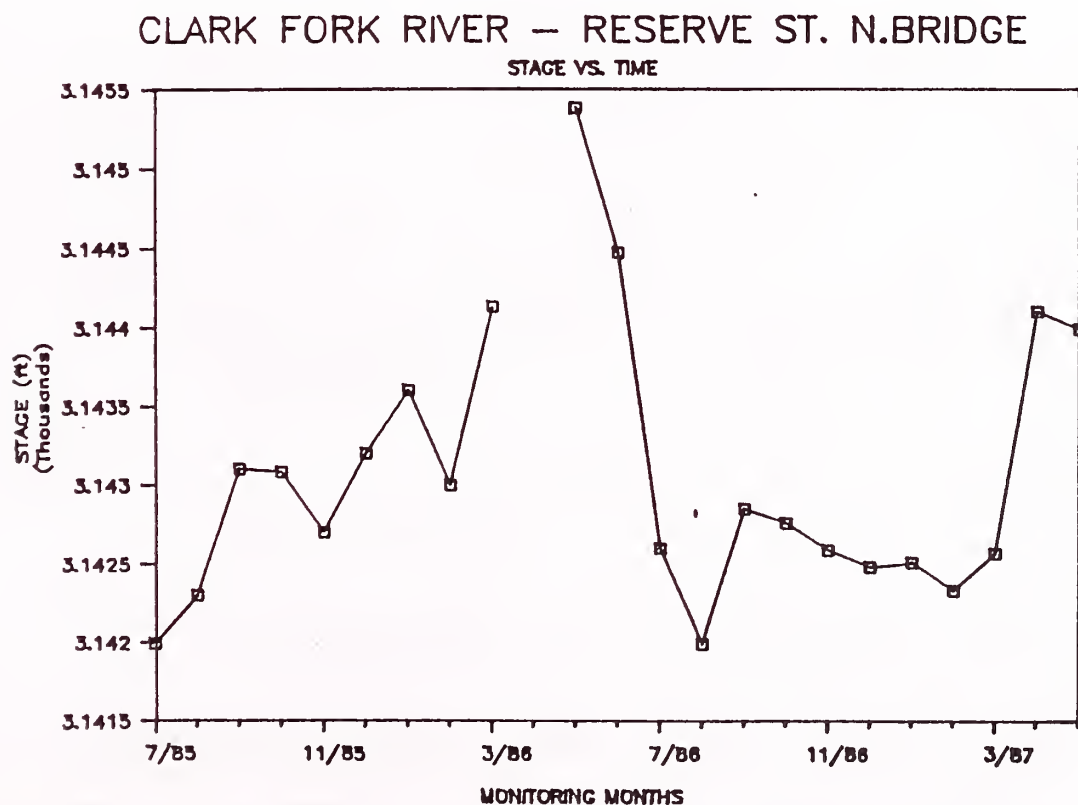
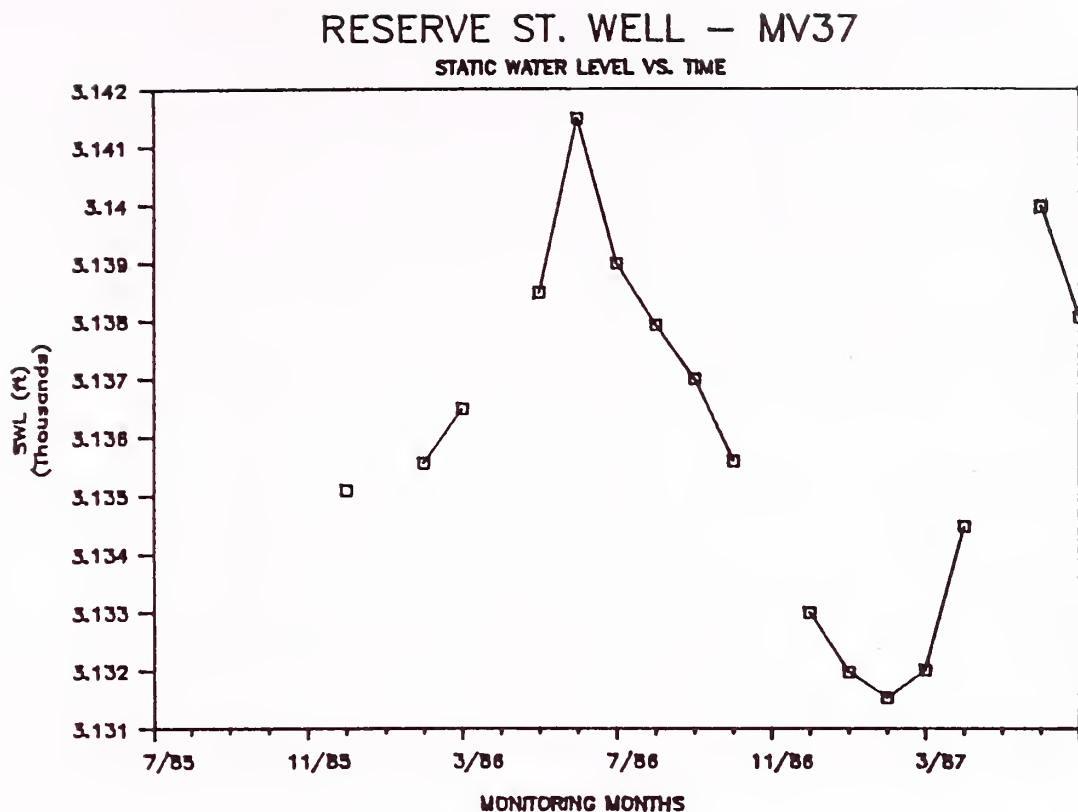
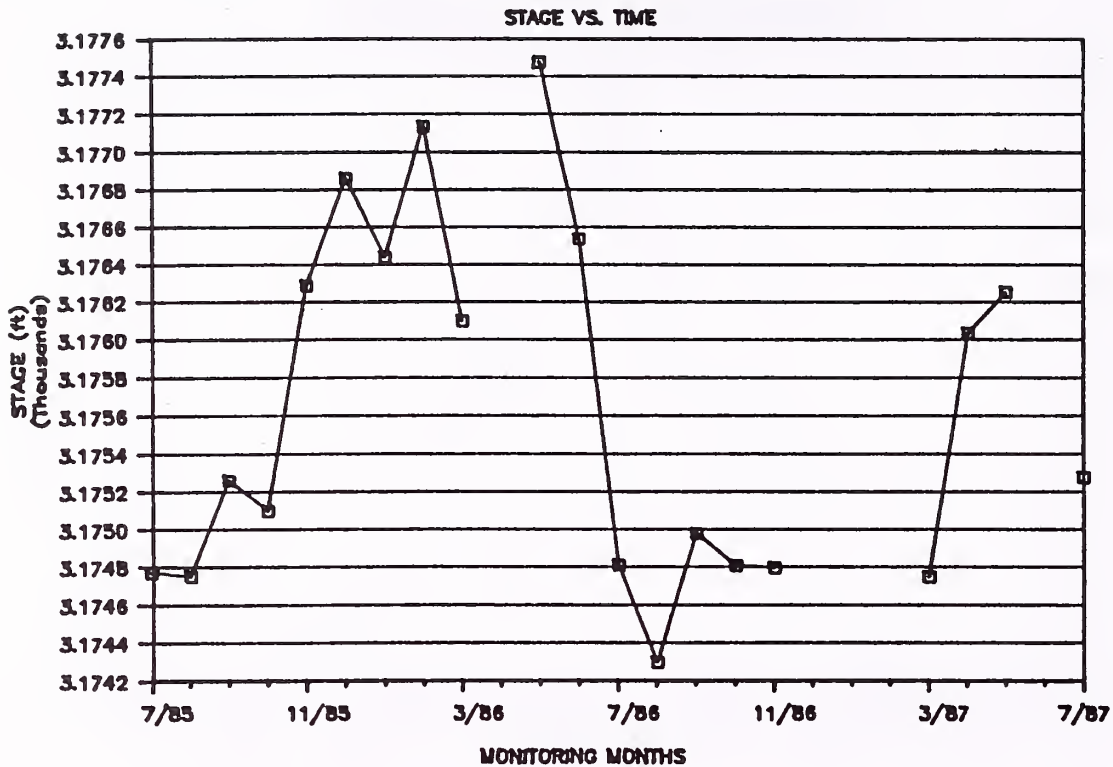


Figure 4.16: Hydrographs of data from well MV37 (top) and the Clark Fork River at the Reserve Street Bridge (bottom).

CLARK FORK RIVER — NORTH WALK BRIDGE



Well Hydrographs

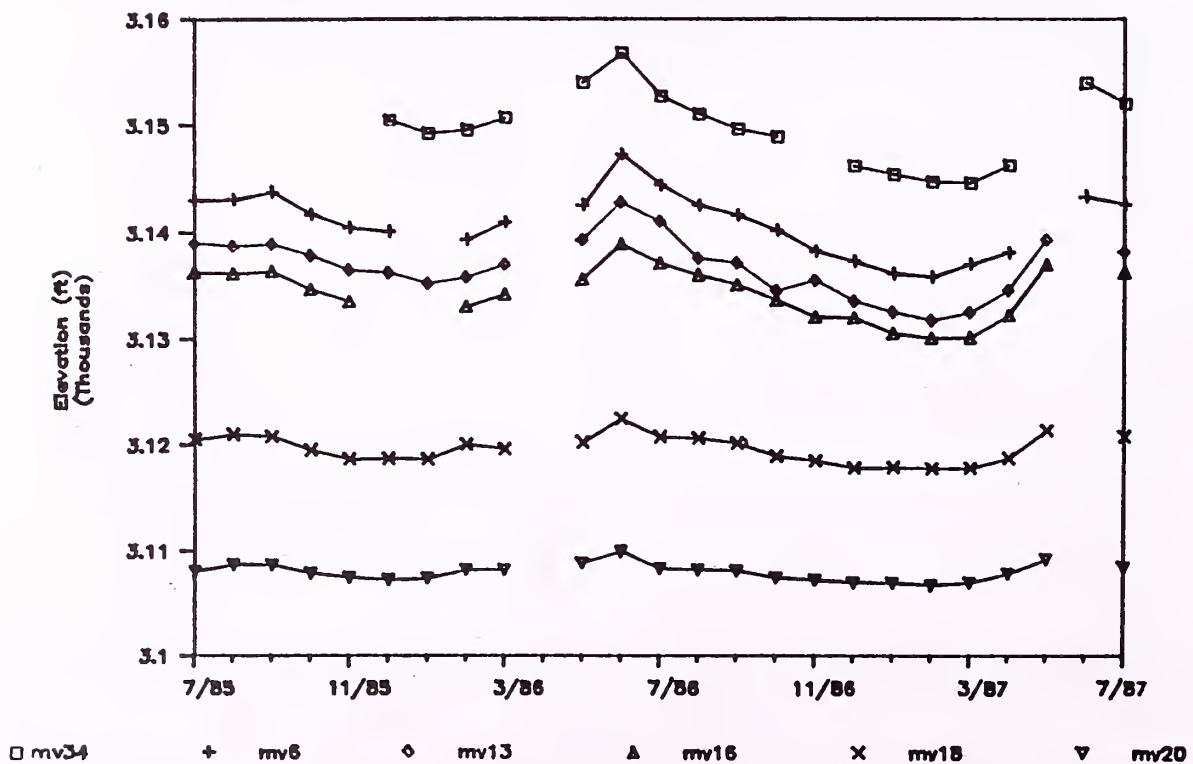
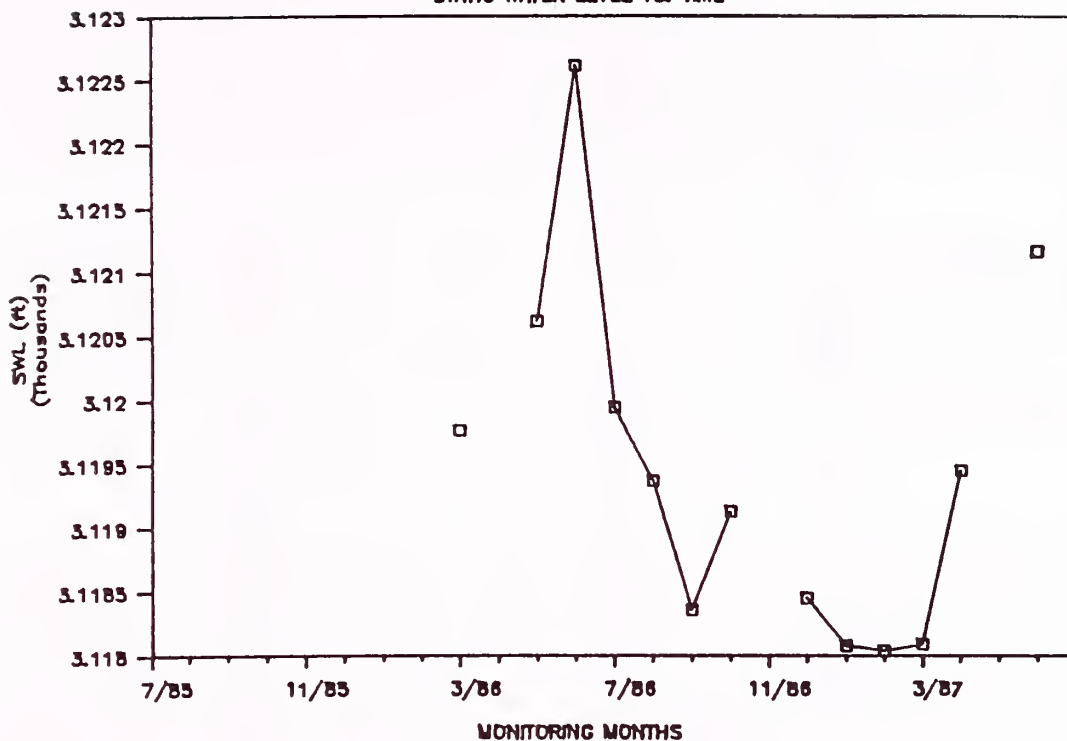


Figure 4.17: Hydrographs of data from the Clark Fork River (top) and wells located progressively further from the river (bottom).

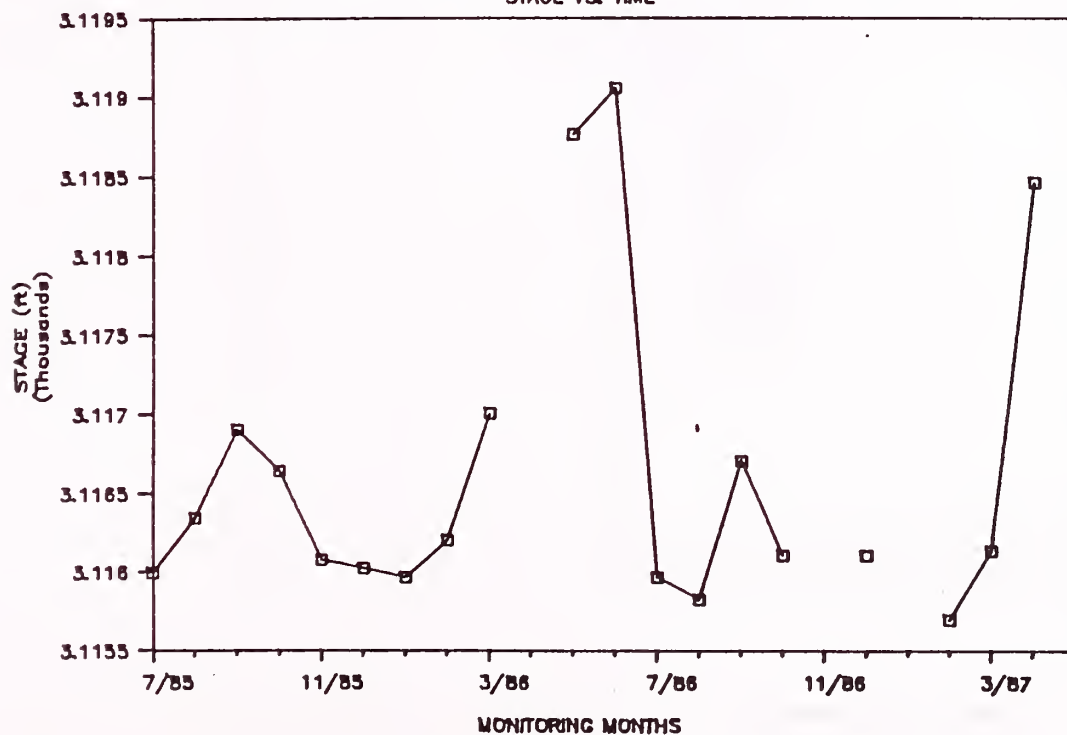
BUCKHOUSE BRIDGE WELL – MV39

STATIC WATER LEVEL VS. TIME



BITTERROOT RIVER – BUCKHOUSE BRIDGE

STAGE VS. TIME



Mountain Water Company Wells

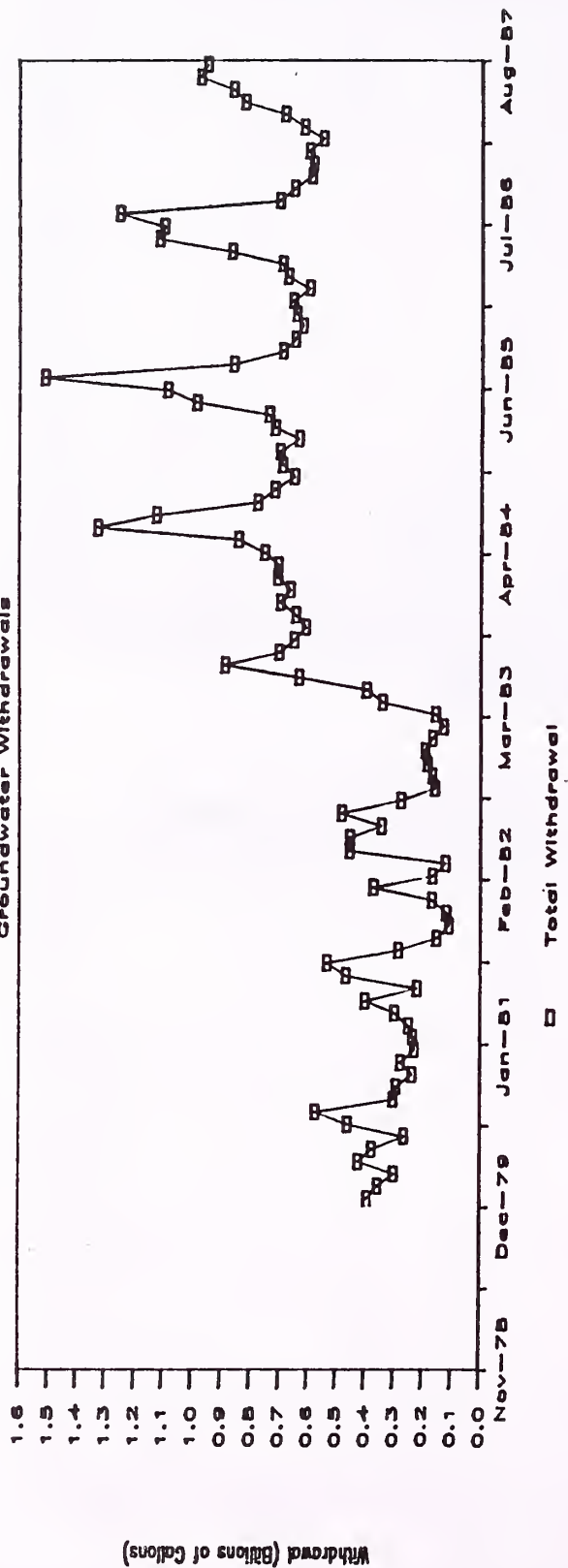


Figure 4.19: Total monthly ground water withdrawals by Mountain Water Company.

The water level trends observed in Figure 4.20 show a general fluctuation between about 3,146 ft to 3,132 ft from 1958 through 1980. From 1980 to 1985 water level data were collected at times which would not reflect periods of highest and lowest water levels so trends are difficult to distinguish with these data. Since 1984, monthly water level data show maximum and minimum values fluctuating between about 3,140 and 3,130 ft.

Review of historical water level records from MWC wells shows trends similar to those of MV31. Figures 4.21 and 4.22 present typical hydrographs for Mountain Water Company wells. The water level trends for wells MWC34 and MWC30, which are located adjacent to the Clark Fork River, fluctuate about ten feet seasonally. They both show an apparent stepwise lowering in water levels in late 1983. A similar, but less pronounced, trend is seen in wells MWC19, located north of the river, and MWC20, located to the south. All of these wells are active pumping wells in the MWC network.

Analysis of the long term water level trends in the valley provides an indication of how the aquifer is responding to climatic influences and pumping stress. The hydrographs presented to illustrate the longer term trends show what appears to be a general lowering of the valley water table since 1983. This trend can be seen by looking at the lower elevations of yearly water table maximums and minimums between 1983 and 1987. This record is too short to adequately assess whether a long term trend of net annual decline is actually occurring. This apparent lowering of the water table can be attributed to the increased withdrawal which Mountain Water Company started in 1983 (Figure 4.19) and below average Clark Fork River annual and peak discharges which also began in 1983 and continued through 1987 (Figure 4.23). It is not possible with just water level trend data to separate entirely the individual affect of each of these factors. The source or sources of water level decline will be examined using a mass balance approach in Chapter 5.

MV31

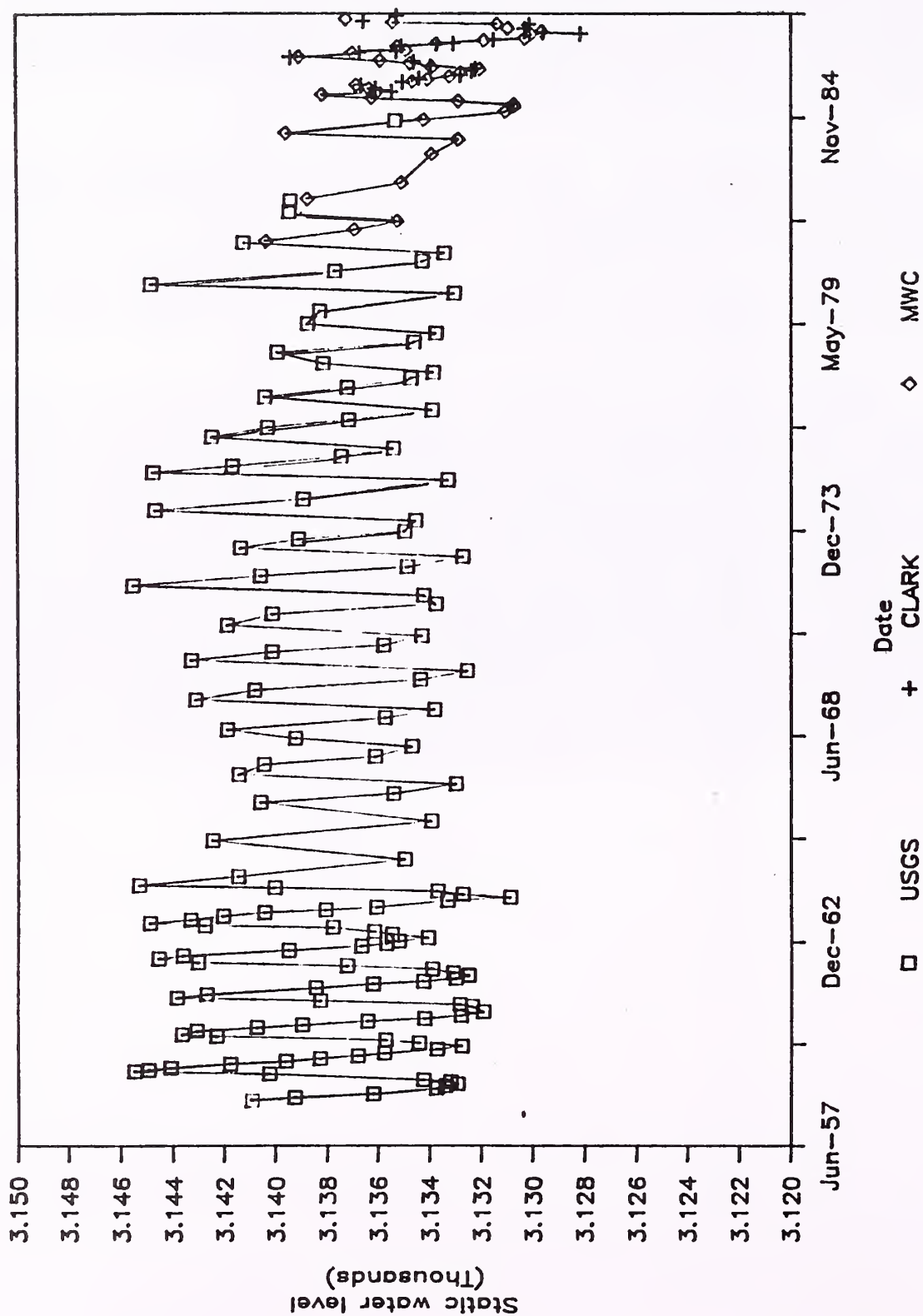
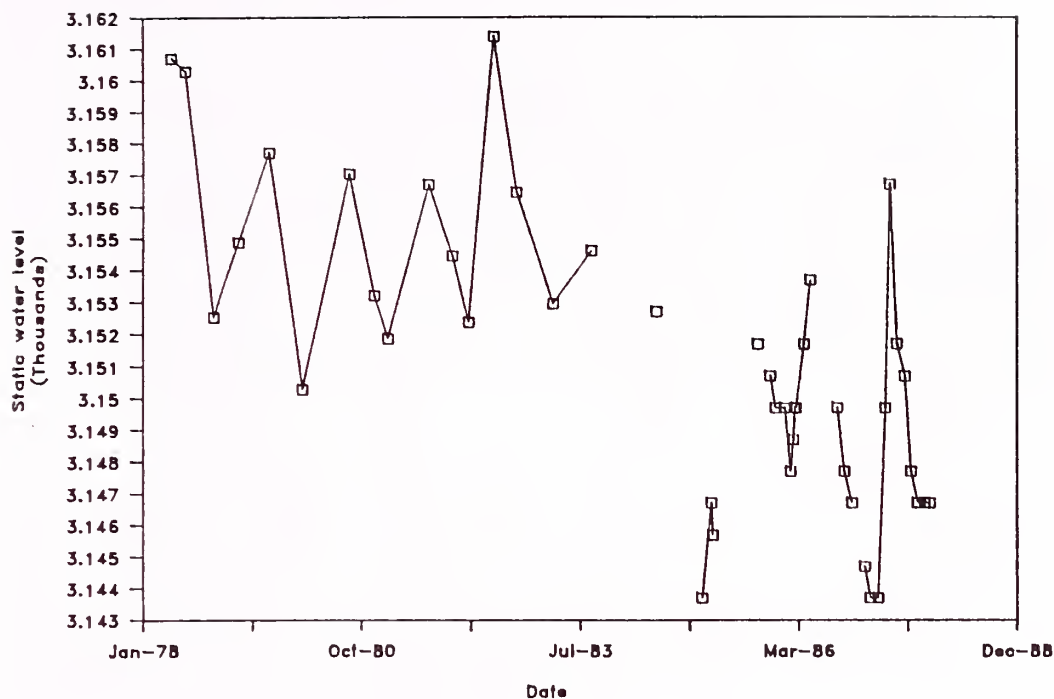


Figure 4.20: Hydrograph of data from well MV31 (MWC7).

MWC34



MWC30

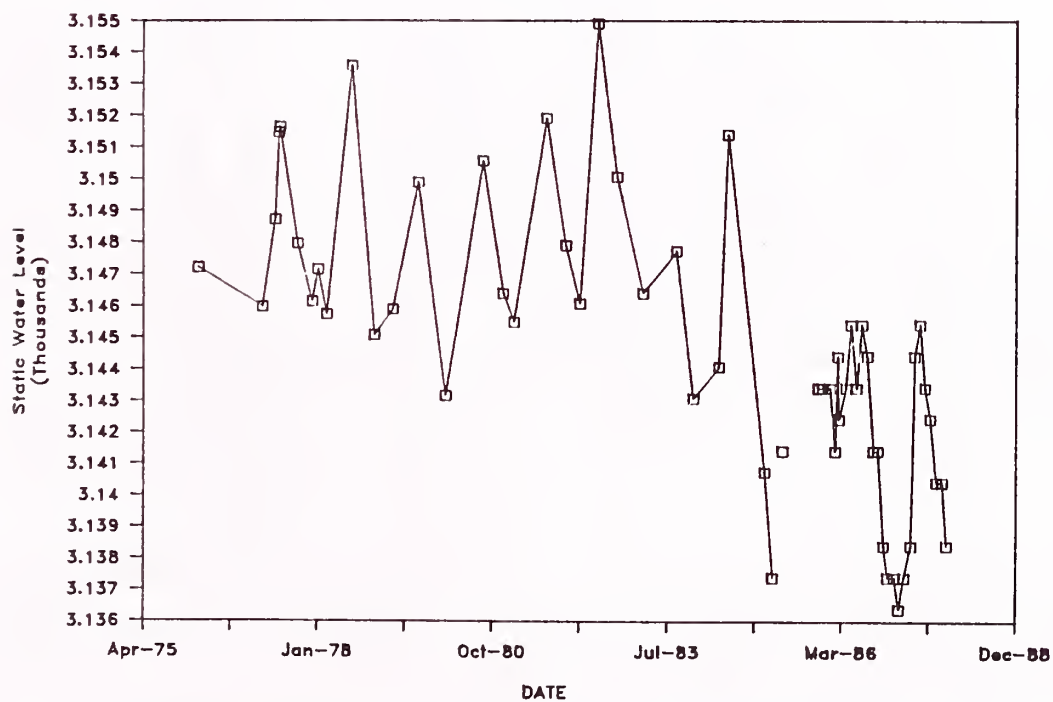
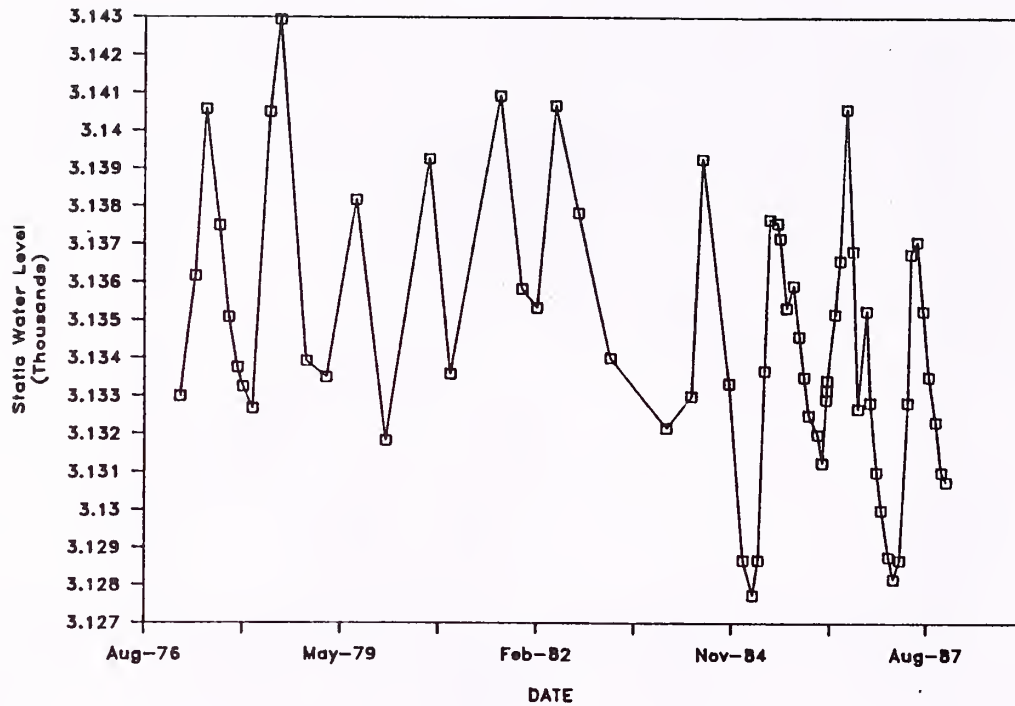


Figure 4.21 Hydrographs of data from wells MWC34 (top) and MWC30 (bottom).

MWC19



MWC20

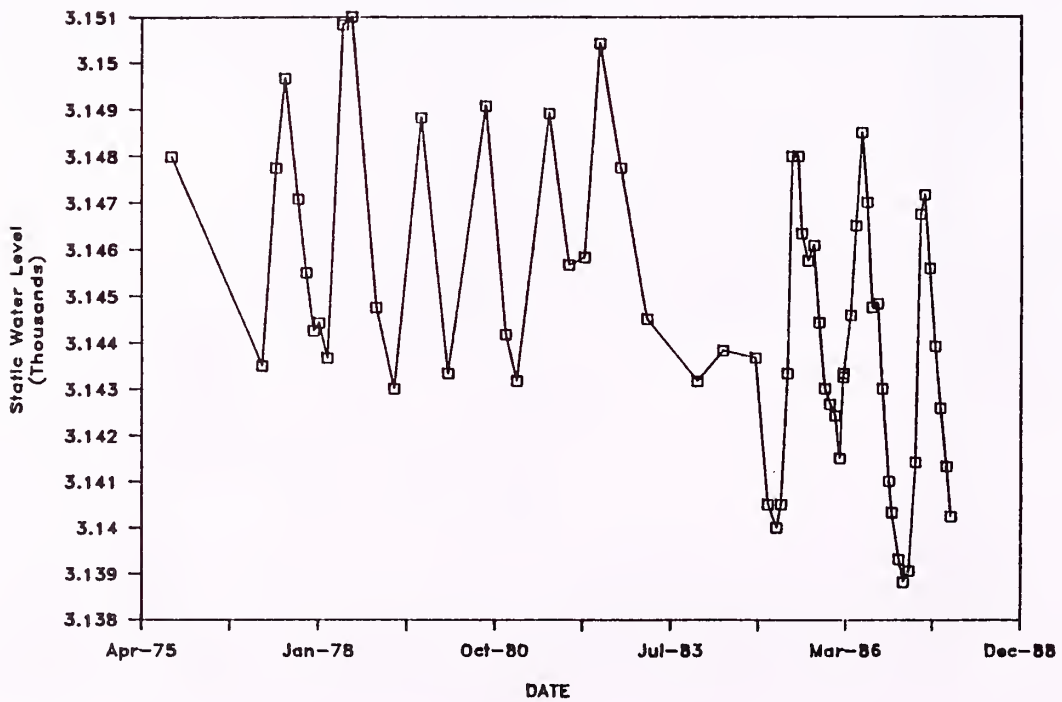
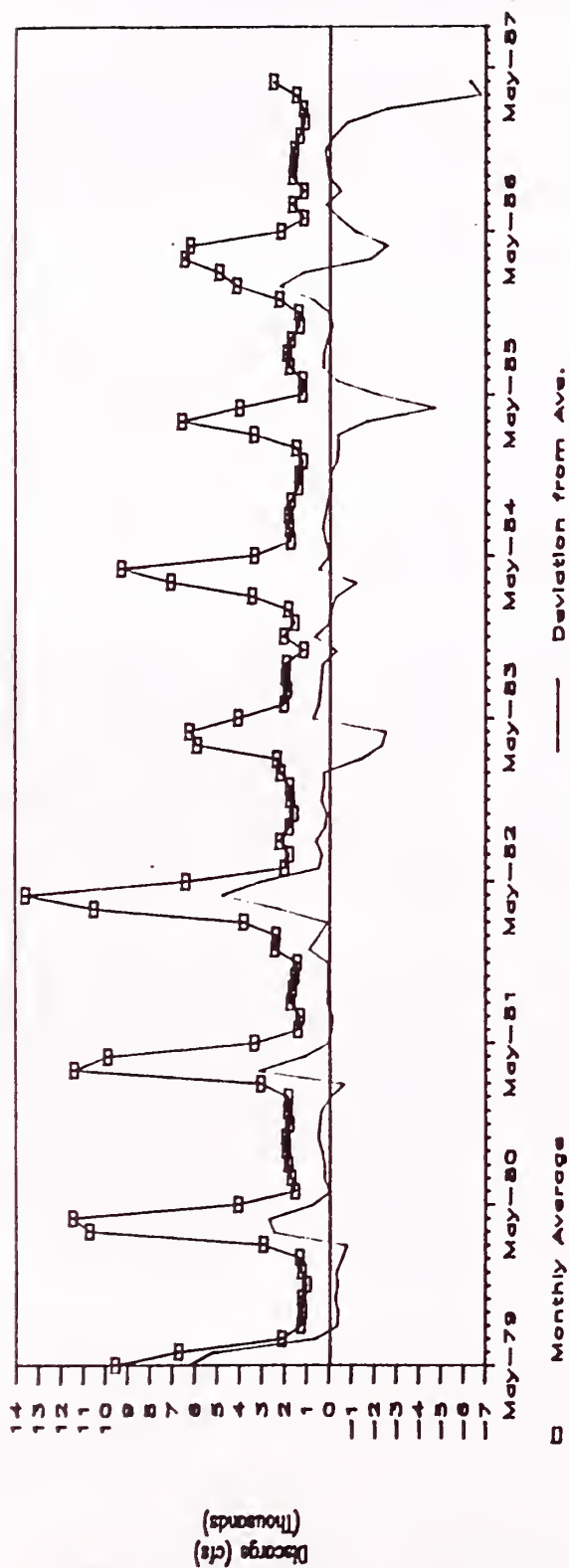


Figure 4.22: Hydrographs of data from wells MWC19 (top) and MWC20 (bottom).

Clark Fork River Above Missoula



Montana Power - MV31

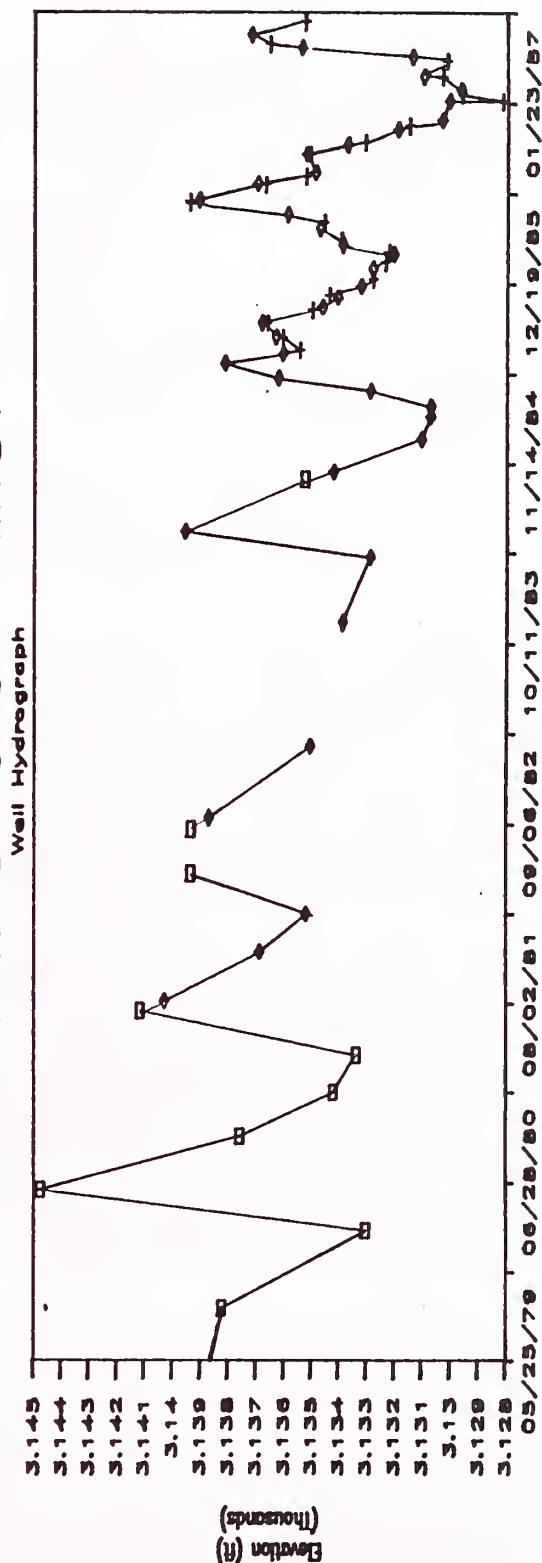


Figure 4.23: Hydrographs of data from well MV31 (MWC7) (bottom) and the Clark Fork River (top) showing the departure from the average monthly discharge.

CHAPTER 5

GROUND WATER FLOW: SOURCES OF RECHARGE AND DISCHARGE

Chapter 4 described the monitoring well network established during this project and the variations in water table elevations which occurred in the Missoula Aquifer. This chapter describes aquifer recharge and discharge, general ground water flow paths and seasonal variations in the flow field.

GROUND WATER FLOW SYSTEM

Monthly water table elevations collected at over 50 wells were plotted and contoured to produce maps showing the configuration of the top of the saturated zone in the aquifer. Three of these potentiometric maps are presented (Figures 5.1 to 5.3) as examples of water level fluctuations and variations in flow paths during 1986. The months selected were:

1. March, when the water table was at its lowest for the year;
2. June, when water levels were highest; and
3. October, as water levels were declining.

The same general pattern of ground water flow is maintained during most of the year. North of the Clark Fork River, ground water moves away from the channel and away from the northern aquifer boundary, where ground water from the Tertiary sediments and the alluvium in the Grant Creek and Rattlesnake Creek Valleys recharges the aquifer. The net result is ground water migration parallel to the river channel and final discharge to the Clark Fork River north of the river's confluence with the Bitterroot River. South of the river ground water flows southwest towards the Bitterroot River and towards the confluence of the Clark Fork and Bitterroot Rivers.

By comparing the water table elevations adjacent to the Clark Fork River with a river channel profile derived from USGS topographic maps, it is evident that the stream is influent over a reach downstream of Hellgate Canyon (Figure 5.4). The length of the influent reach varies seasonally, from about four miles during June and July when the water table is at its highest and over six miles during the winter and spring. Figure 5.4 also shows that the largest differences between the elevations of the river channel and water table occur in the first three to four miles below Hellgate Canyon. Water level trends discussed in Chapter 4 and water quality data presented in Chapter 6 also indicate that the Clark Fork River recharges the aquifer.

Variations in the rate at which the Clark Fork River and other sources recharge the aquifer are reflected in the buildup of the water table in the late spring and early summer, and its subsequent decline from mid summer through late winter. A decrease in recharge from late June to the following March caused the 3,135 ft equipotential line to migrate over two miles to the northeast (Figure 5.5). The almost identical position of the this equipotential line southwest of the first two miles of river channel from December through March probably implies that aquifer recharge and discharge relationships have stabilized. During the same period, additional migration

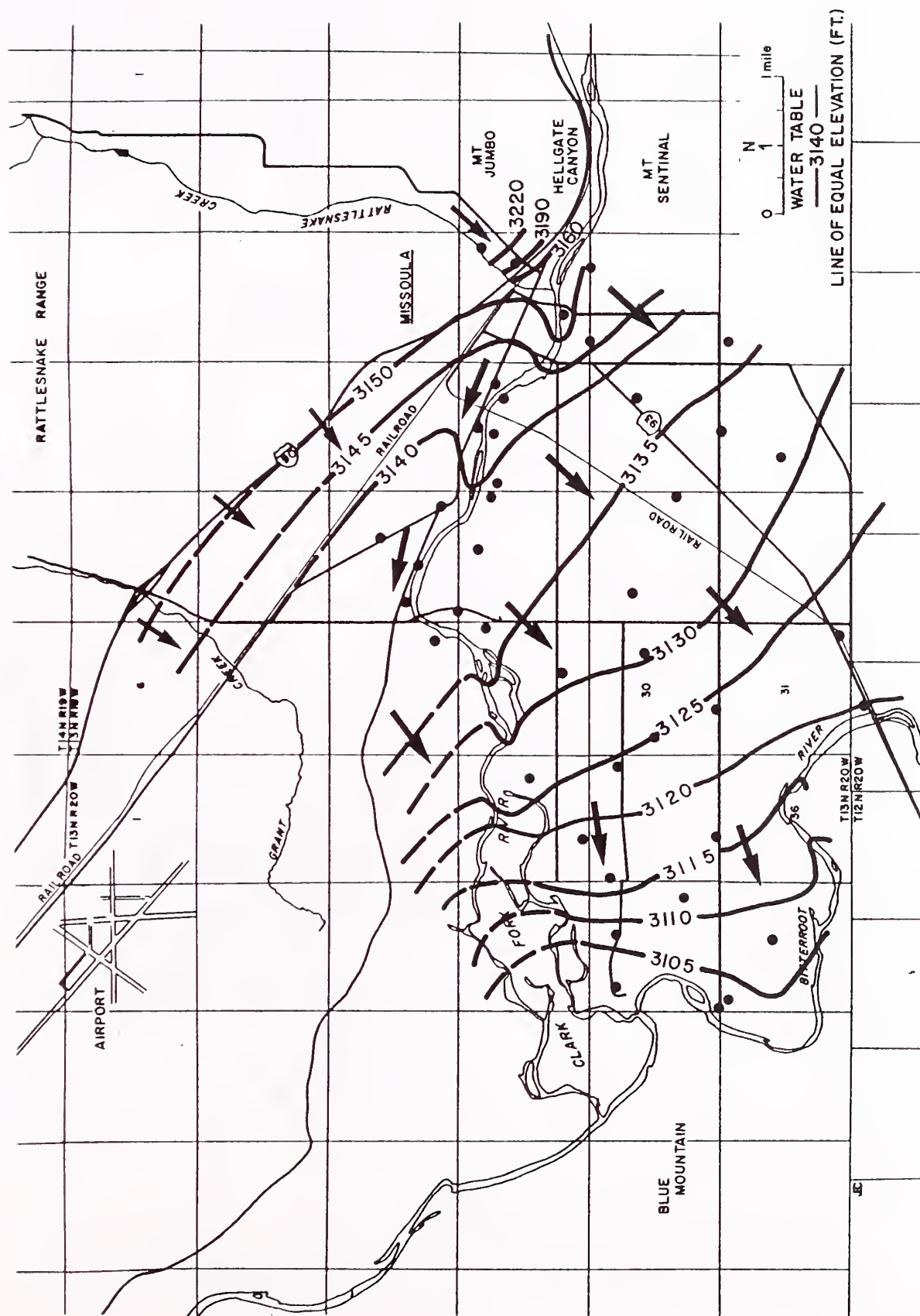


Figure 5.1: Water table map for March 1986. Arrows indicate general direction of ground water flow.

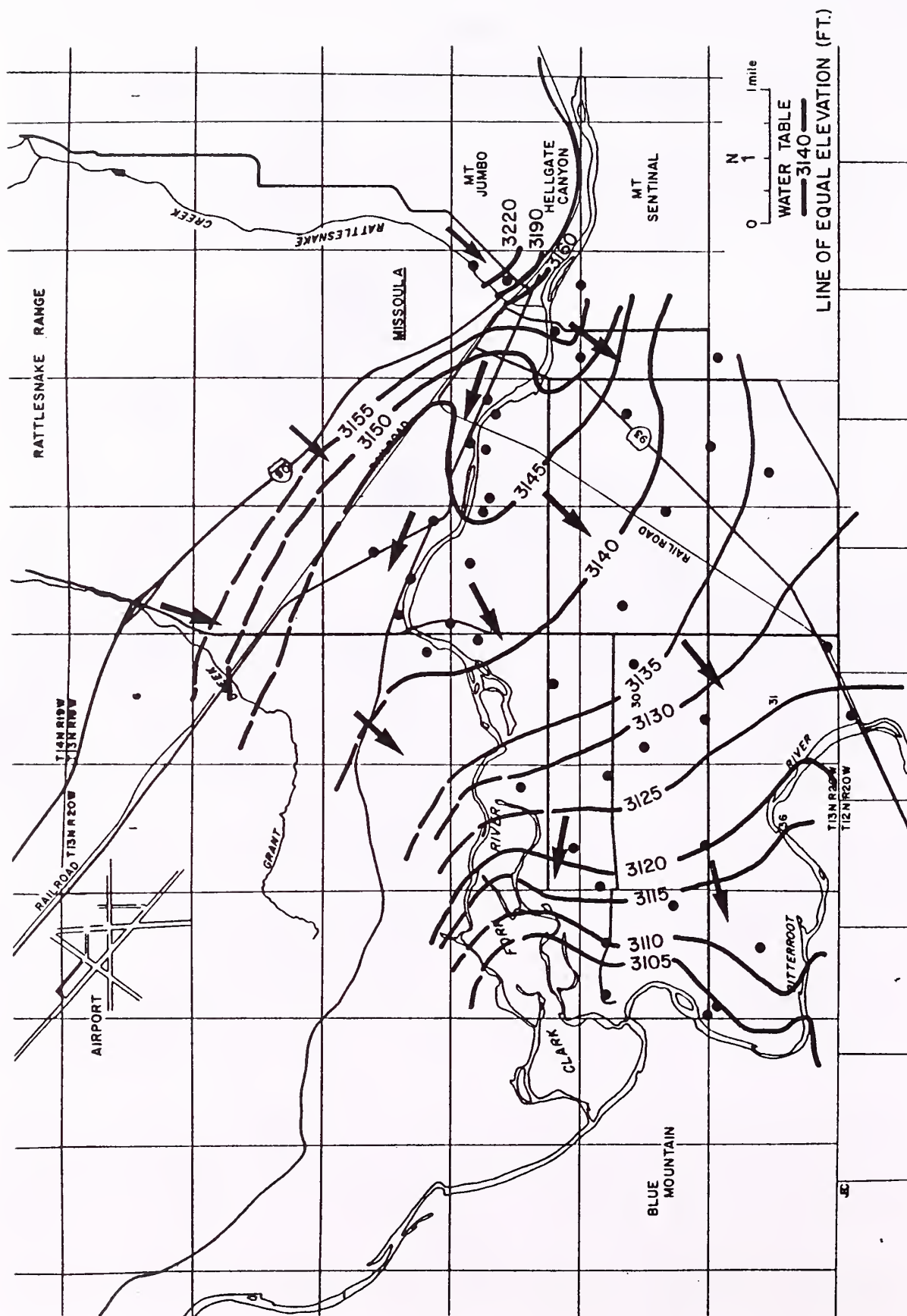


Figure 5.2: Water table map for June 1986. Arrows indicate general direction of ground water flow.

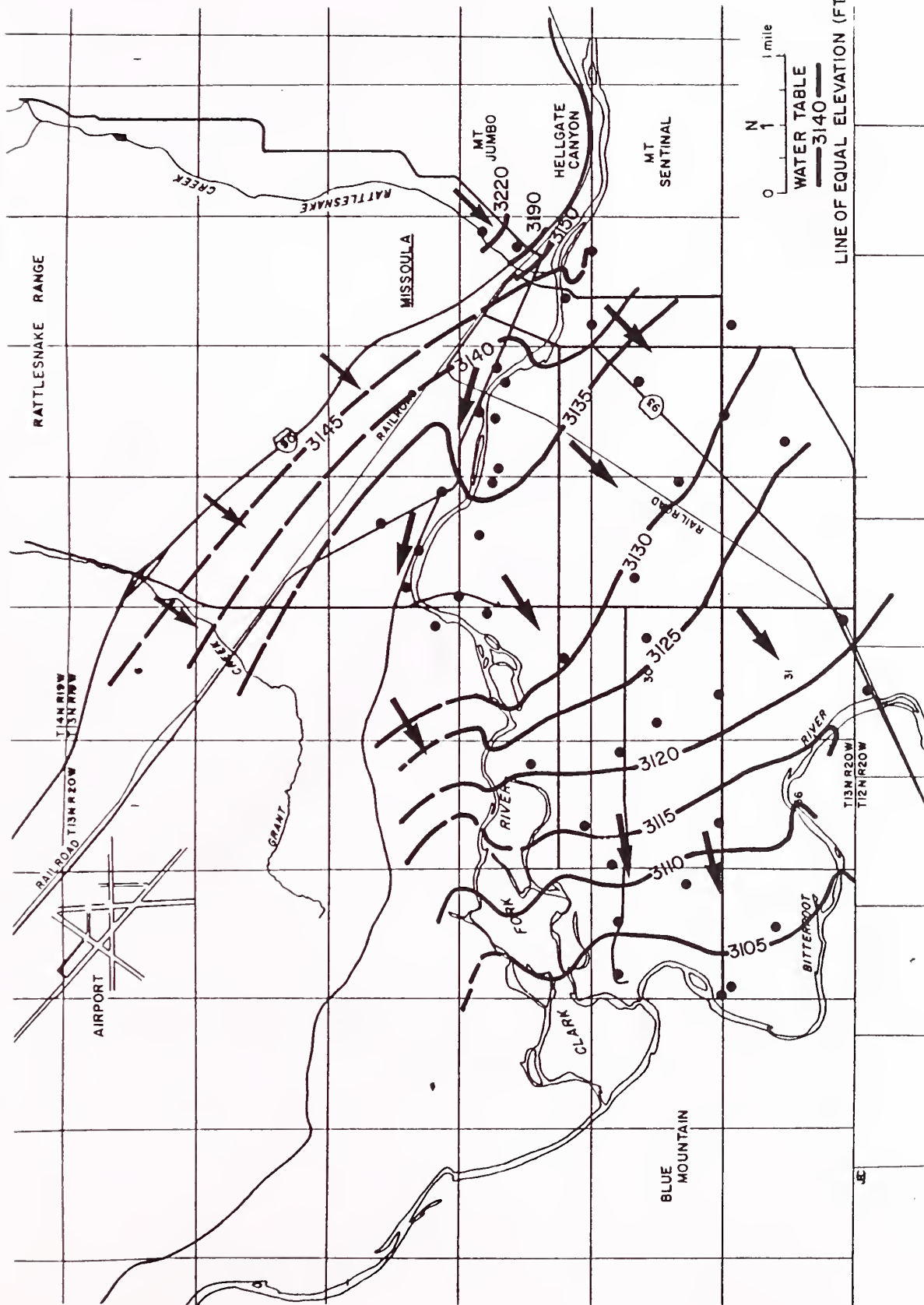


Figure 5.3: Water table map for October 1986. Arrows indicate general direction of ground water flow.

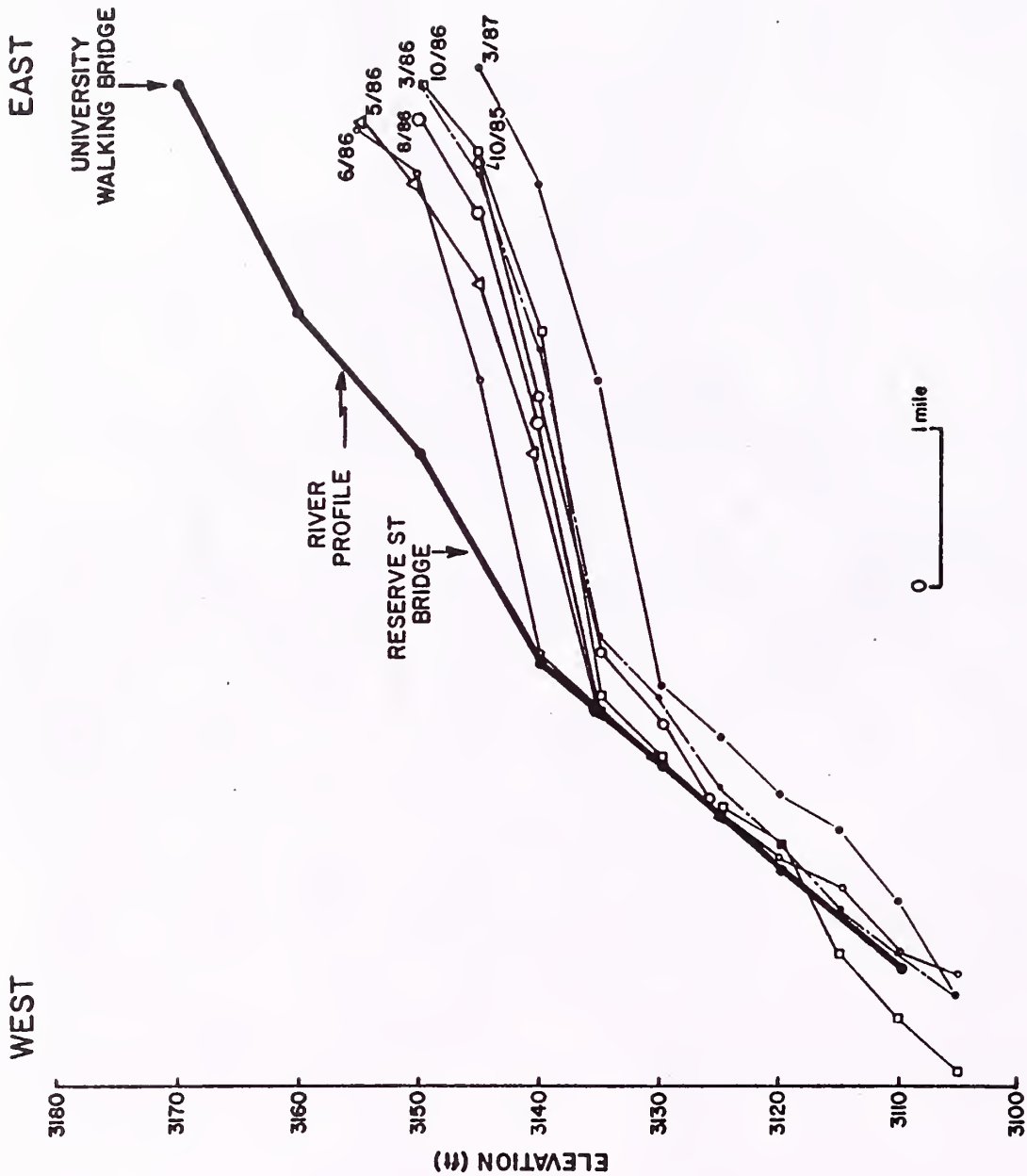


Figure 5.4: Clark Fork River channel profile and the corresponding elevation of the water table.

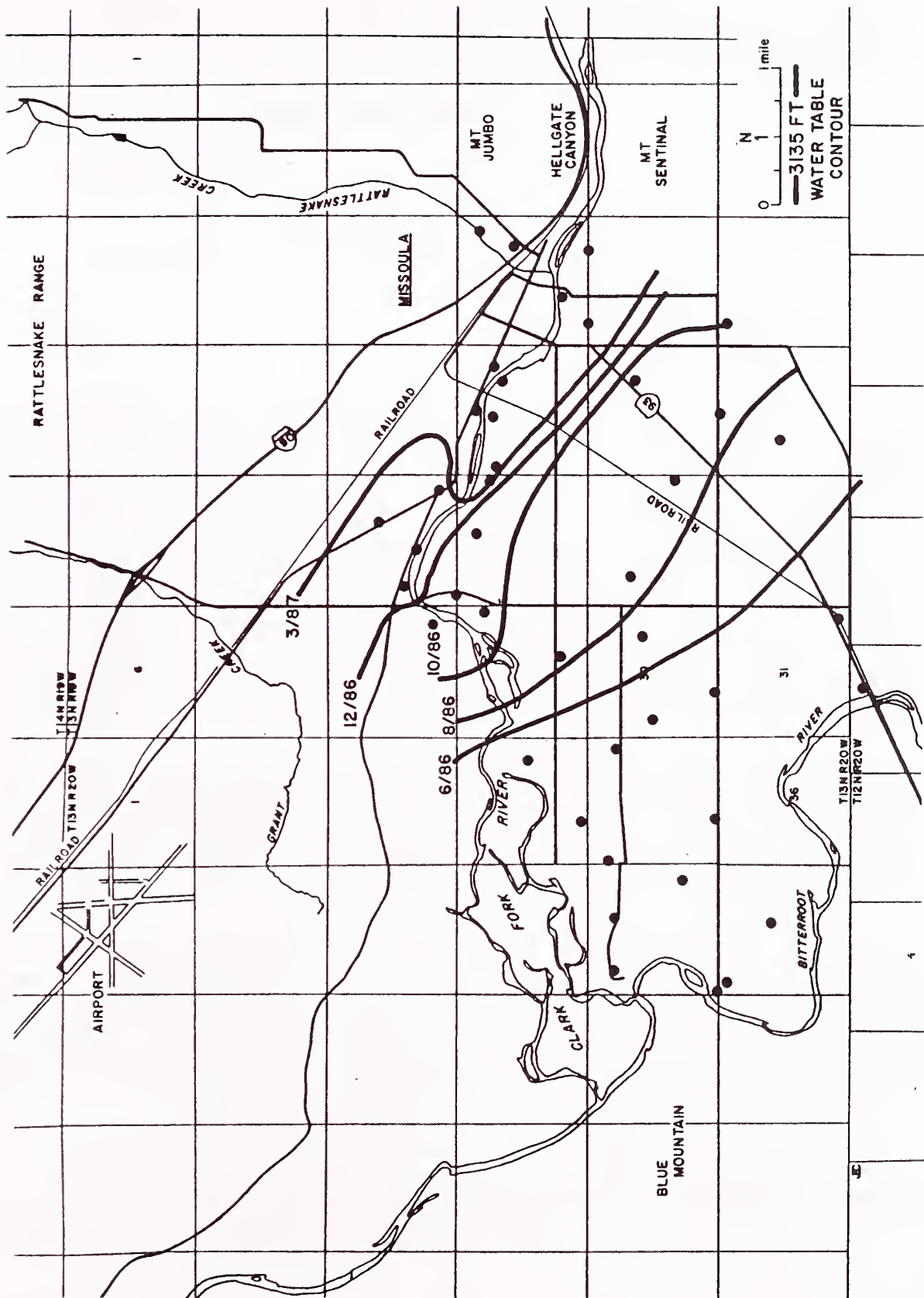


Figure 5.5: Changes in the location of the 3,135 ft equipotential line during the water table decline from June 1986 to March 1987.

of the 3,135 ft equipotential line is observed north of the river in the vicinity of the Reserve Street Bridge. This trend is most likely controlled by a decline in recharge from the influent Grant Creek and a continuing seasonal reduction in recharge from the Tertiary sediments to the north.

AQUIFER RECHARGE AND DISCHARGE

Water recharges the Missoula Aquifer from a number of sources:

1. Influent reaches of the Clark Fork River;
2. Direct precipitation on the aquifer;
3. Discharge from the adjacent Tertiary Sediment and Bedrock Hydrostratigraphic Units;
4. Storm water runoff;
5. Septic systems; and
6. Leakage from irrigation ditches.

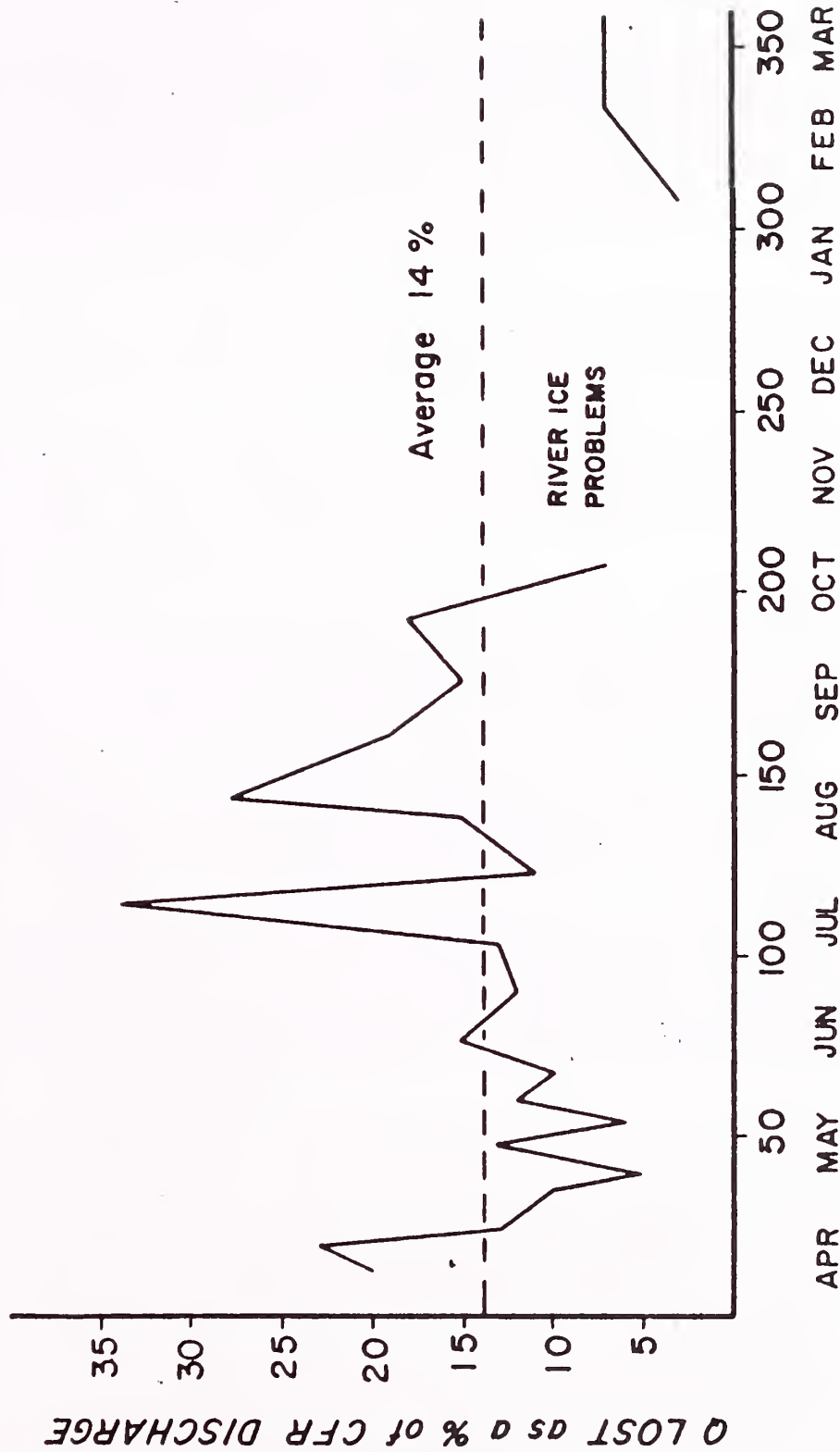
Leakage from the Clark Fork River in the valley is the major source of recharge to the Missoula Aquifer. Clark (1986) attempted to quantify the recharge from a three mile reach of the river by measuring the loss in streamflow between the University Walking Bridge (about 0.5 mi from the mouth of the Hellgate Canyon) and the Reserve Street Bridge. After accounting for irrigation diversions in this reach and inflow from Rattlesnake Creek, he concluded that about 14% of the flow measured at the Walking Bridge, or 324,700 acft/yr, leaked through the streambed and recharged the aquifer (Figure 5.6). Clark's (1986) calculations were further refined by incorporating the variations in the length of the influent reach of the river and by estimating monthly instead of annual seepage losses (Figure 5.7). The revised estimate of leakage from the river is 412,700 acft/yr. Leakage calculations are explained in Appendix 5A.

The role of direct precipitation on the unconfined aquifer has not been quantified. If precipitation contributes to aquifer recharge at all, it probably occurs only in the spring associated with snow melt and spring rainfall. By July, all rainwater not entering the Missoula storm water systems is probably evapotranspired. From November to March, the ground is frozen and recharge from the surface does not occur.

Spring precipitation and snowmelt compose the principal recharge to bedrock and Tertiary sediments which underlie surrounding highlands. Water from these hydrostratigraphic units then recharges the Missoula Aquifer through lateral inflow. Equipotential lines indicate a source of recharge from the mountainous terrain north of the valley (Figures 5.1 to 5.3). These sediments do yield small volumes of water to wells; equipotential surfaces in these sediments are higher than in the Missoula Aquifer.

The annual ground water discharge from the hills on the aquifer's northern boundary was estimated by assuming an aquifer thickness of 75 ft, a hydraulic conductivity of 100 ft/d and a hydraulic gradient of 0.006 for this 6.75 mi boundary (Pottinger, 1988). Calculated discharge is 13,400 acft/yr.

MASS BALANCE RESULTS



DAYS since April 1, 1985

Figure 5.6: Percentage of discharge, measured at the Walking Bridge, recharging the aquifer over a three mile reach of the river.

MONTHLY LEAKAGE FROM CFR

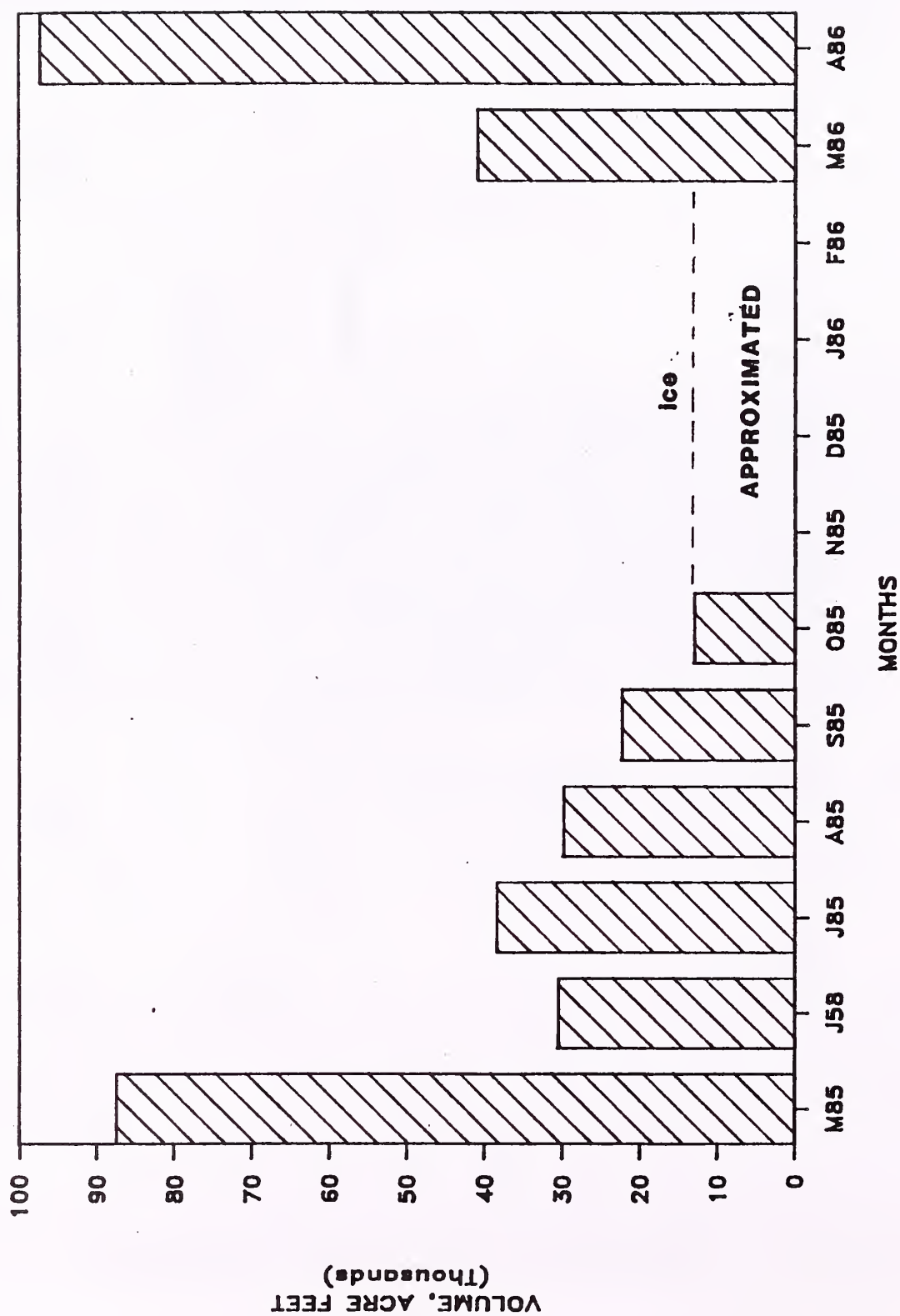


Figure 5.7: Calculated average monthly loss from the Clark Fork River.

Some minor recharge may also come from the hills on the east and southeast of the valley and from underlying formations. These sources were not quantified.

Ground water flow from other small stream valleys is an additional source of recharge in the northern portion of the aquifer. Sendler (1986) estimated that 350 acft/yr of ground water discharges from the Rattlesnake Creek alluvium to the Missoula Aquifer. du Breuil (1983) estimated ground water recharge from the Grant Creek Valley at 4,900 acft/yr. Smaller streams, such as Pattee Creek and Butler Creek, also are influent as they enter the Missoula Valley. Their recharge rates were not quantified.

Storm water runoff in the Missoula area is channeled into over 2,000 dry wells which allow water to percolate to the water table. Wogsland (1988) estimated that 365 acft of water are injected annually.

Septic systems service all but the main Missoula metropolitan area. Over 5,700 individual residences are found in the valley with an additional 600 in the Rattlesnake Creek Valley. Ver Hey (1987) measured daily loading of about 250 gpd per household. Based on her research, about 1,600 acft/yr of septic wastes recharge the aquifer.

Geldon (1979) attempted to quantify the seepage from irrigation ditches and irrigated areas for the immediate area around Missoula. Though values have not been derived for the entire aquifer, his results provide an approximation good to an order of magnitude. He estimated that irrigation practices account for approximately 8,500 acft/yr of aquifer recharge.

In the Missoula area, losses from Mountain Water Company's distribution system are estimated to be over 12,250 acft/yr, assuming a 50 percent loss of the water produced. Table 5.1 summarizes the sources of recharge to the Missoula Aquifer.

Water which discharges from the aquifer by evapotranspiration and as base flow to streams has not been quantified. Evapotranspiration is probably an important source of aquifer discharge in riparian areas along streams and from subirrigated fields west of the confluence of the Bitterroot and Clark Fork Rivers.

Ground water is pumped from wells owned by individuals, industrial users, and two private water companies, Mountain Water Company and Clark Fork Water Company (CFWC). For the last two years MWC and CFWC have produced an average of over nine billion gallons per year from the aquifer. About 45,000 people live within MWC's service area and on the average use 550 gallons per person per day (MCCHD, 1987). This daily use rate is high because of the 50 percent water loss from the distribution system. The Clark Fork Water Company serves 2,329 people, who each use about 360 gallons daily. An estimated 4,700 families are served by single or multi-family wells outside of the water company service areas. Each family is assumed to use about 320 gpd (MCCHD, 1987). Total annual withdrawal from wells is estimated at 30,210 acft.

TABLE 5.1
Volume Estimates of Recharge to the Missoula Aquifer

Source	Amount	
	acft/yr	% of total
Septic systems	1,600	0.4
Rattlesnake Creek Valley	350	0.07
Storm Water*	365	0.08
Grant Creek**	4,900	1.0
Irrigation***	8,500	1.9
MWC line loss	12,300	2.7
Lateral inflow, north	13,400	3.0
Clark Fork River	412,700	90.9
TOTAL	454,115	

(*Missoula area)

(**No other creeks quantified)

(***Only in the immediate Missoula area)

The volume of natural discharge from the Missoula Aquifer was approximated (assuming no net change in storage) by subtracting the estimated annual recharge to the aquifer (Table 5.1) from the annual withdrawal from wells (Table 5.2). The estimated annual discharge is 423,905 acft.

TABLE 5.2
Water Use from the Missoula Aquifer

	Population	Use Per Capita	
		Daily (gpd)	Annual (acft/yr)
Mountain Water Company	44,755	550	27,570
Clark Fork Water Company	2,329	360	940
Households with private wells	4,700	320*	<u>1,700</u>
		Total	30,210

(*gallons per household)

In summary, aquifer recharge exceeds estimated ground water discharge and withdrawal by 15 times. The leakage of water through the bed of the Clark Fork River accounts for over 90% of the annual recharge. Therefore water table declines noted in Chapter 4 most likely reflect recent climatic conditions which have caused reductions in recharge rates from the river and from Tertiary sediments. Water levels may decline locally in areas of heavy pumping, particularly during periods of low recharge, but in general, current levels of ground water withdrawal do not appear to be over drawing the aquifer.

CHAPTER 6

AQUIFER WATER QUALITY

This chapter includes a discussion of sampling methodology, general aquifer chemistry, results of an intensive sampling of the aquifer west of Reserve Street and summaries of three ground water quality research efforts conducted in conjunction with and partially support by this study.

METHODS

Twenty-six monitoring wells, six Mountain Water Company wells, and two locations on both the Clark Fork and Bitterroot Rivers were sampled five times on a quarterly basis between February 1986 and May 1987 (Figure 6.1). All samples were analyzed for gross ionic chemistry by Dr. Juday (Department of Chemistry, University of Montana). Energy Labs of Billings, Montana, determined dissolved trace metal content of samples from 14 of the 26 sites. Standard sampling and analytical procedures were exercised. Analytical data are presented in Appendix 6A and 6B.

The quality control program utilized duplicates, blanks, and standards. Three sample duplicates and three blanks were added to each group of 26 samples delivered to the laboratories for gross ionic analysis. Each batch of trace metal samples had one blank, one duplicate, and one trace metal standard (prepared from National Bureau of Standard's SRM #1643b.)

The last quarterly sampling (spring 1987) included an expanded set of monitoring wells. Sixty-eight domestic wells located west of Reserve Street plus 28 sites in the quarterly monitoring network (Plate 1) were sampled for gross ionic chemistry and coliform bacteria (Figure 6.2). Gross chemistry analyses were performed by Dr. Juday. Coliform analyses were completed by the Missoula City County Health Department. Sixty-six dissolved trace metal analyses were done by Dr. Moore (Department of Geology, University of Montana). Sampling followed standard procedures. A quality control program similar to the one described above was used.

In June 1987, six ground water samples were collected and analyzed for an EPA priority pollutant scan, which includes analyses for pesticides, PCB's, and purgable, acid extractable and base neutral organic compounds. Standard procedures were followed when sampling and analyses were performed using EPA standard procedures by Lancaster Laboratories of Lancaster, Pennsylvania. Blanks and duplicates were not included for quality control because of the high cost of analysis and the limited sampling budget.

RESULTS: GENERAL DESCRIPTION OF GROUND WATER QUALITY

The ground water in the Missoula Aquifer is a calcium bicarbonate type. Near the Clark Fork River, the mineral content of ground water fluctuates seasonally in response to changes in river water quality. Throughout the rest of the aquifer, mineral content remains essentially constant at any one point but increases in the direction of ground water flow. Detectable metal

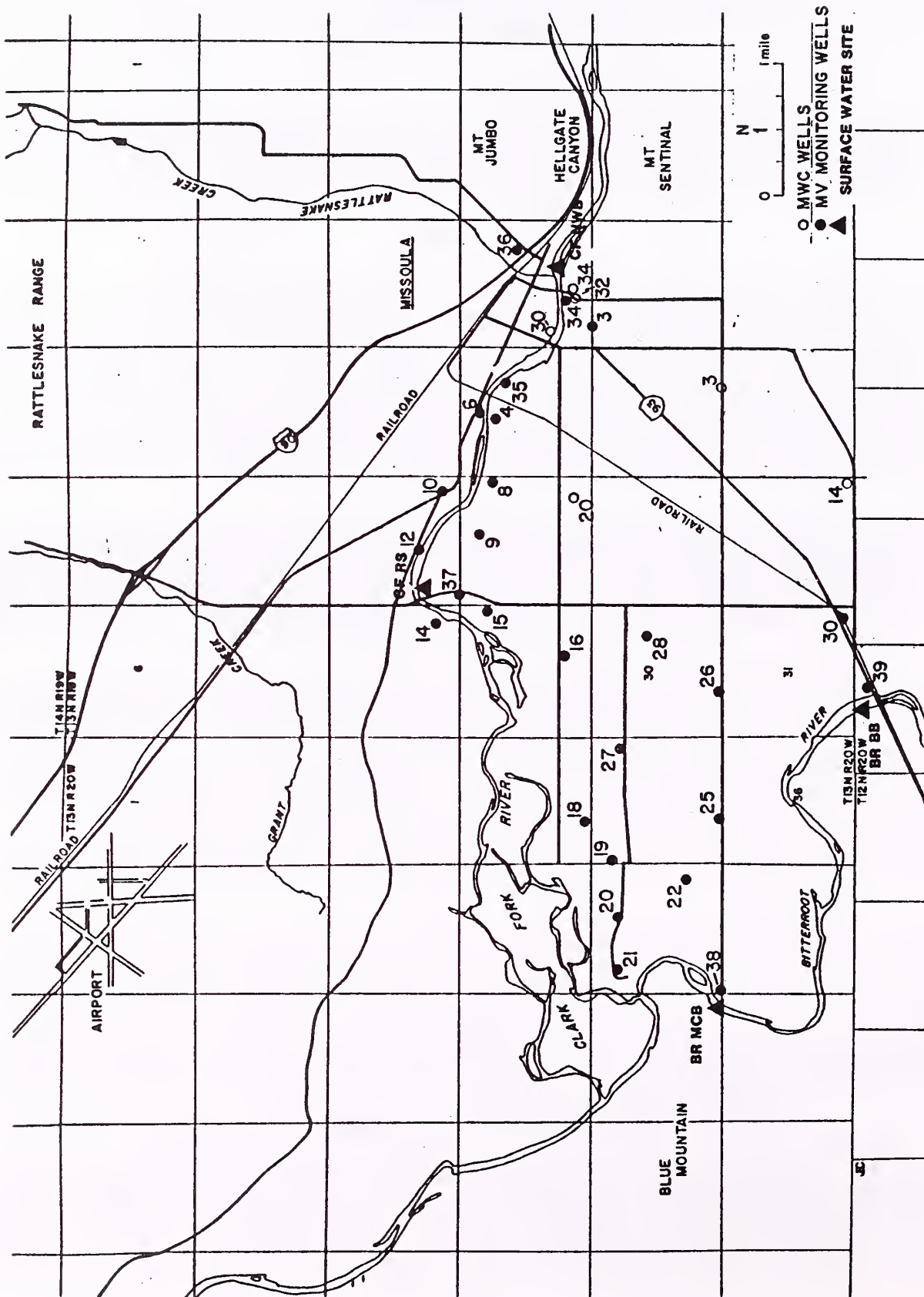


Figure 6.1: Project water quality monitoring network.

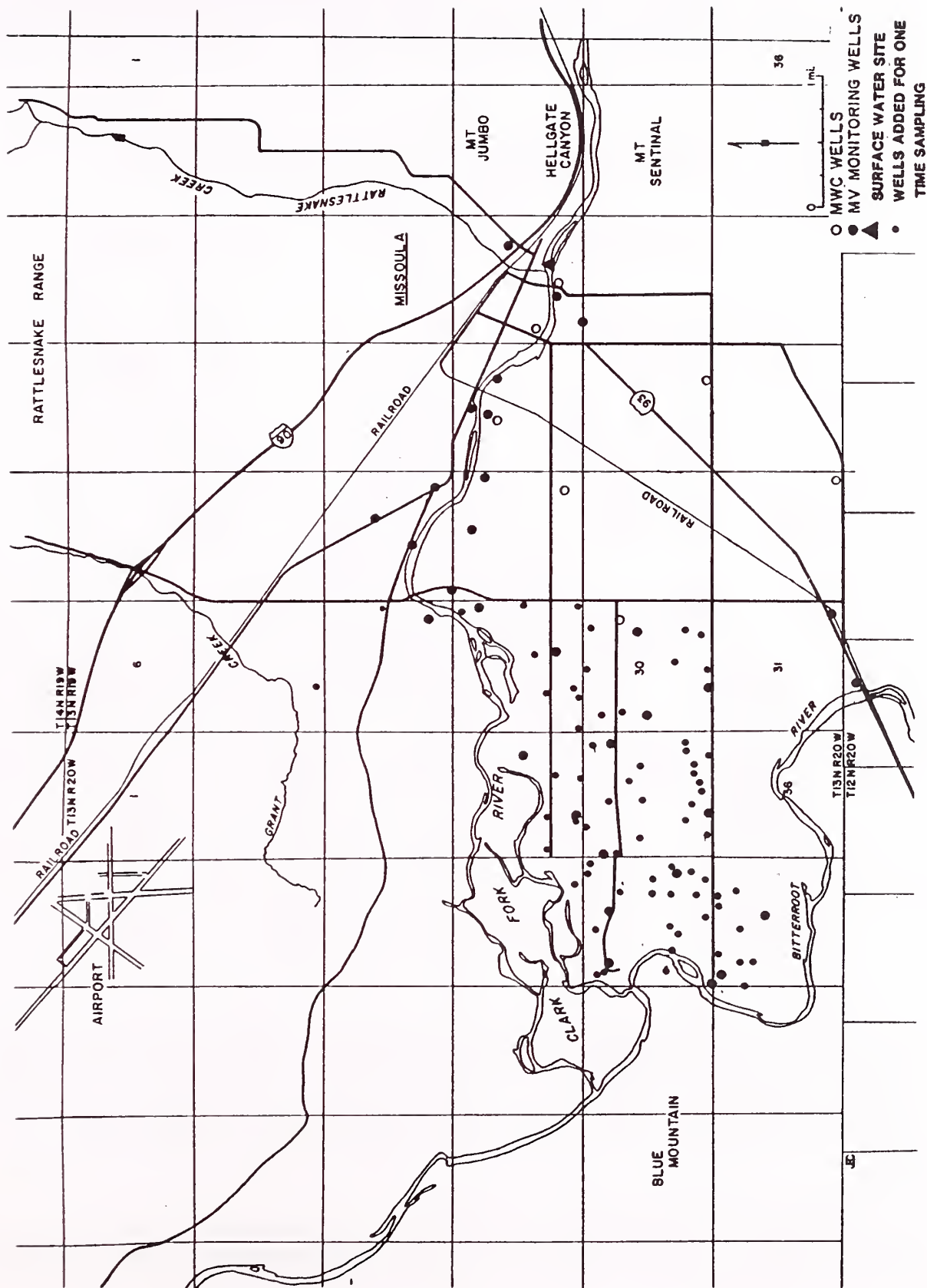


Figure 6.2: Location of water quality sampling sites for the spring 1987 monitoring.

concentrations occur primarily in Clark Fork River water and in adjacent wells. Stiff diagrams indicate the relative proportion of major ions in ground water throughout the aquifer (Figure 6.3). Average and representative water analyses are shown in Tables 6.1 and 6.2.

TABLE 6.1
Water Analyses of Representative Missoula Valley
Ground Water Samples Collected February 5, 1986
(mg/l)

Parameter	Up gradient MV34	Down gradient MV25
Bicarbonate	177.9	199.3
Chloride	2.46	5.55
Sulfate	19.3	22.1
NO3 (as N)	0.41	1.13
Calcium	41.3	47.0
Magnesium	11.6	14.4
Sodium	5.9	7.4
Potassium	1.3	2.0
TDS	261.6	302.6

TABLE 6.2
Average Water Quality for All Water Analyses
(mg/l, n = 222)

Parameter	Average	Minimum	Maximum	Std. Deviation
Bicarbonate	187.4	77.5	237.8	26.5
Chloride	3.85	0.52	13.2	1.6
Sulfate	21.5	1.4	40.5	6.2
NO3 (as N)	0.76	0.1	1.9	0.4
Calcium	44.9	16.5	57.1	5.8
Magnesium	12.9	1.9	18.5	2.0
Sodium	6.97	2.7	12.1	1.2
Potassium	1.78	0.7	2.6	0.3
TDS	282.7	113.4	357.8	35.9

Seasonal variations in water quality occur in the Clark Fork River and nearby wells. The fluctuations water chemistry in these wells and the river (Figure 6.4) are synchronous both temporally and in magnitude and, therefore, provide confirmation that the aquifer is recharged by the river. At distances over one half mile from the river, ground water quality remains fairly constant with time at any one well (note wells MV16, MV27 and MV20 in Figure 6.4).

Metals are primarily found in the Clark Fork River and in wells near the river. Copper is the exception and was detected randomly in about one third

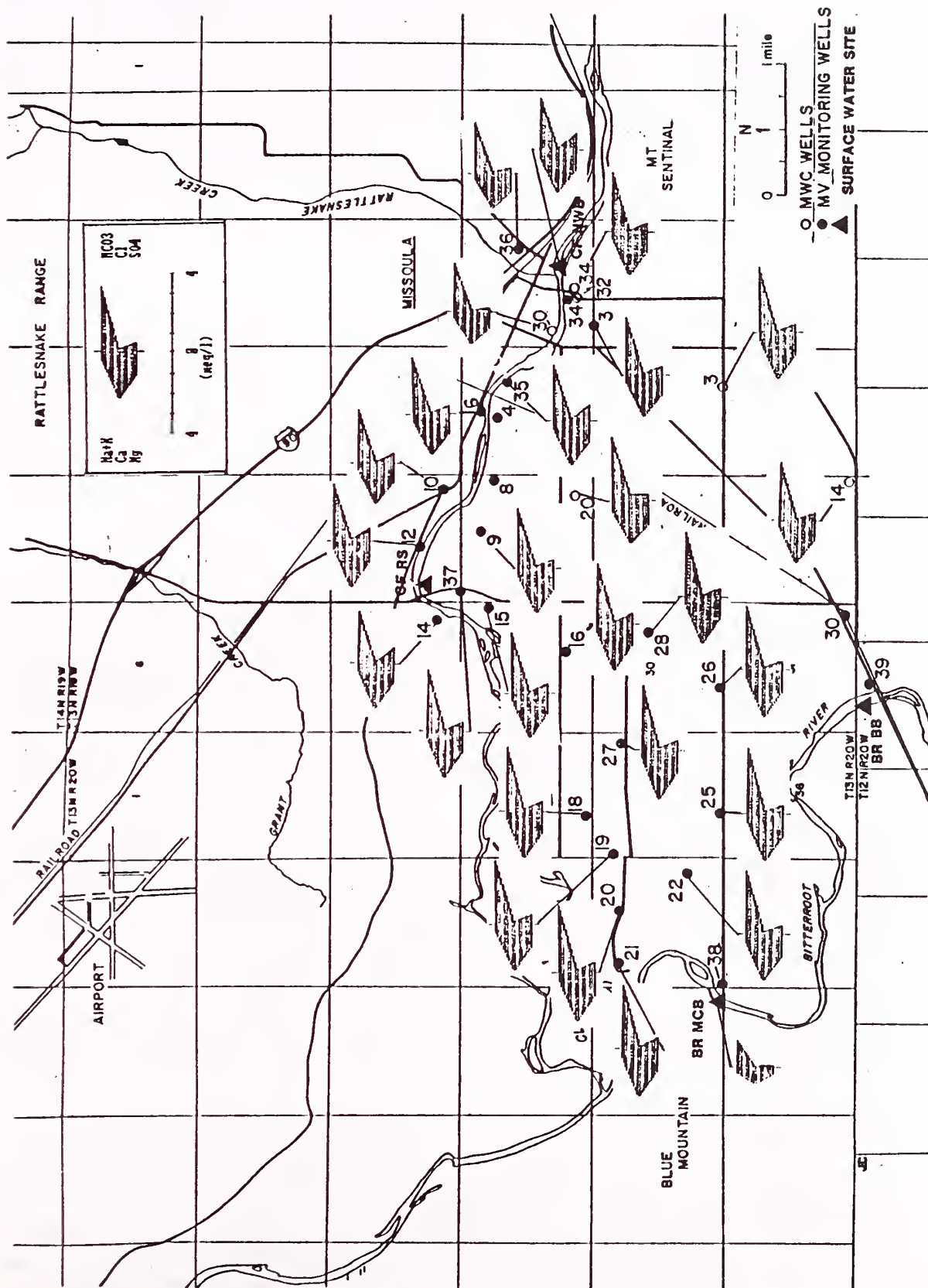
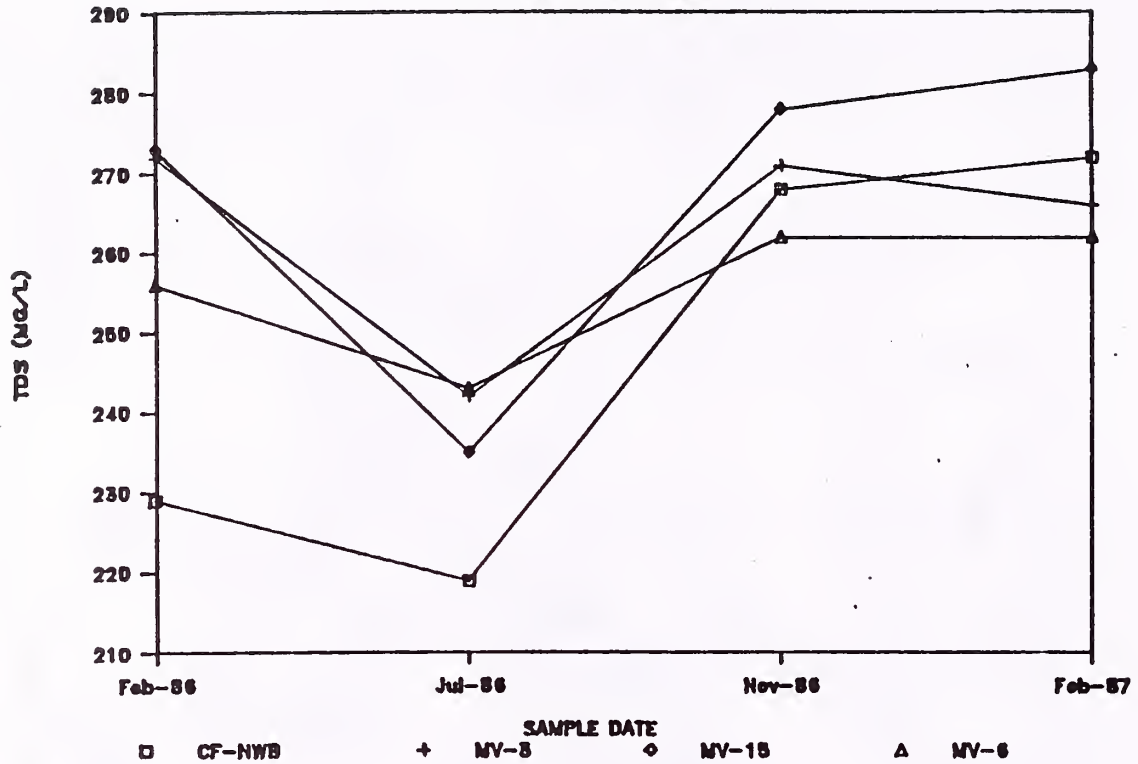


Figure 6.3: Distribution of major cations and anions, November and December 1986.

MISSOULA VALLEY AQUIFER

TOTAL DISSOLVED SOLIDS



MISSOULA VALLEY AQUIFER

TOTAL DISSOLVED SOLIDS

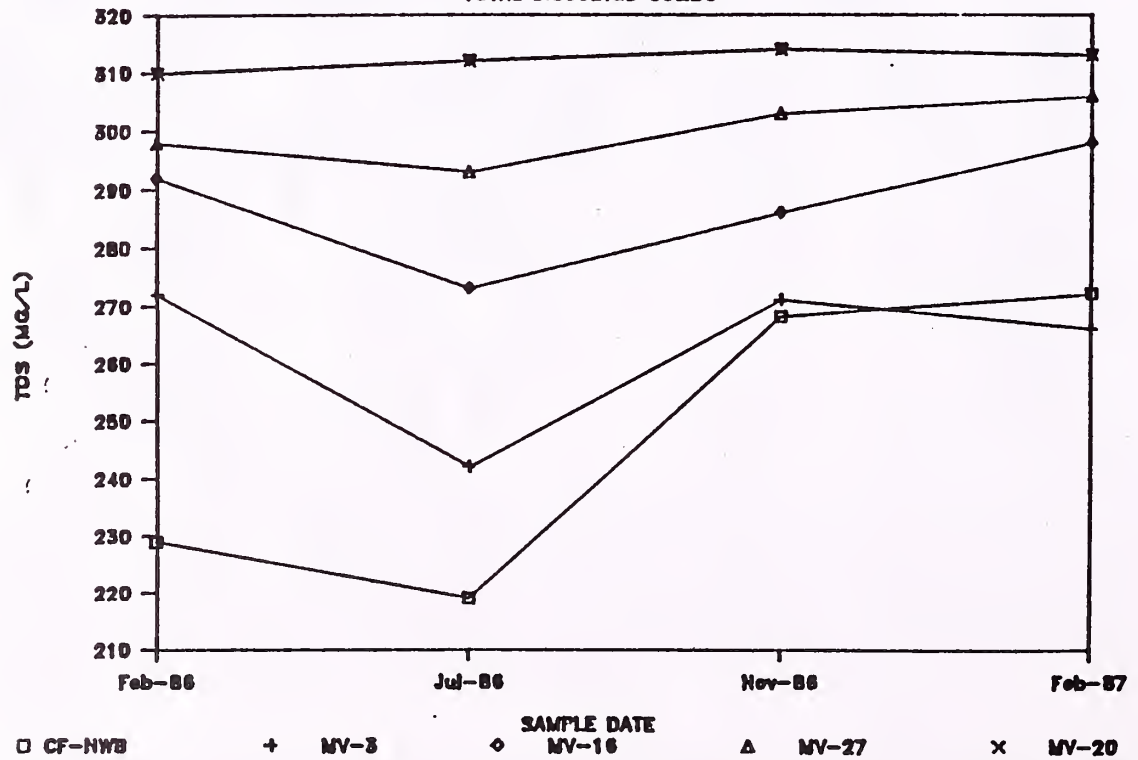


Figure 6.4: Hydrographs showing seasonal variation in TDS for the Clark Fork River and adjacent wells (top) and seasonal change in TDS along a ground water flow path from CFNWB to MV20 (bottom).

of the wells throughout the valley. With one exception (MV38), measured metal concentrations did not exceed drinking water standards. The Clark Fork River had detectable levels of arsenic, zinc, and copper in November 1986, but at other times all metals were at or below detection levels. Wells MV3, MV8 and MV10 had elevated levels of zinc and copper. Well MV38 had a manganese concentration of 0.17 mg/l and was the only well sampled with manganese above the detection level. These four wells are all within one quarter mile of the Clark Fork River. Their elevated levels of metals may be related to unidentified metal contaminated sediments in the Clark Fork River floodplain. However, there are many other wells in close proximity to the river which do not have detectable levels of metals. Concentrations of lead, mercury, and cadmium are all at or below their detection levels.

Results of trace metal analyses should be viewed with caution and only as trends because all sampled wells (except MV41 and MV42) had steel casings and most samples were collected through the household plumbing. To reduce the potential of metal contamination, samples were collected only after the well and piping system had been flushed with fresh ground water and the water temperature and specific conductance had stabilized.

CHEMICAL TRENDS: RESULTS OF SPRING 1987 SAMPLING

Early in the project a review of aquifer stratigraphy and water quality data indicated that the western portion of the aquifer may be susceptible to contamination from individual sewage disposal systems. This area of the aquifer was not well represented in the water quality sampling network and therefore, an expanded quarterly sampling was carried out in May and June of 1987. Sixty-six additional domestic wells which were volunteered by their owners for sampling were added to this round of sample collection (Figure 6.2). The resulting chemical data are extensive (Appendix 6B) and were used to construct isoconcentrational maps of the aquifer and examine trends in water quality.

Water quality steadily decreases in the down gradient direction from Hellgate Canyon east and southeast toward the Bitterroot River. For example, total dissolved solids increase from a low of about 240 mg/l to a high of 358 mg/l over distances of four to five miles. The distribution of total dissolved solids in the Missoula Valley measured during spring 1987 (Figure 6.5) is very similar to that of the other four sampling periods. Comparison of a potentiometric map (Figure 5.2) and the isoconcentrational map (Figure 6.5) shows that the steady increase in total dissolved solids occurs in the direction of ground water flow. The down gradient increase in total dissolved solids is also apparent in Figure 6.4.

The observed down gradient increase in total dissolved solids is most likely caused by natural dissolution in the aquifer of carbonate minerals, such as calcite and dolomite. The increase in calcium, magnesium and bicarbonate concentrations correlates with the increase in total dissolved solids. Concentrations of other major ions, such as sulfate, sodium, and chloride, do not correlate with total dissolved solids.

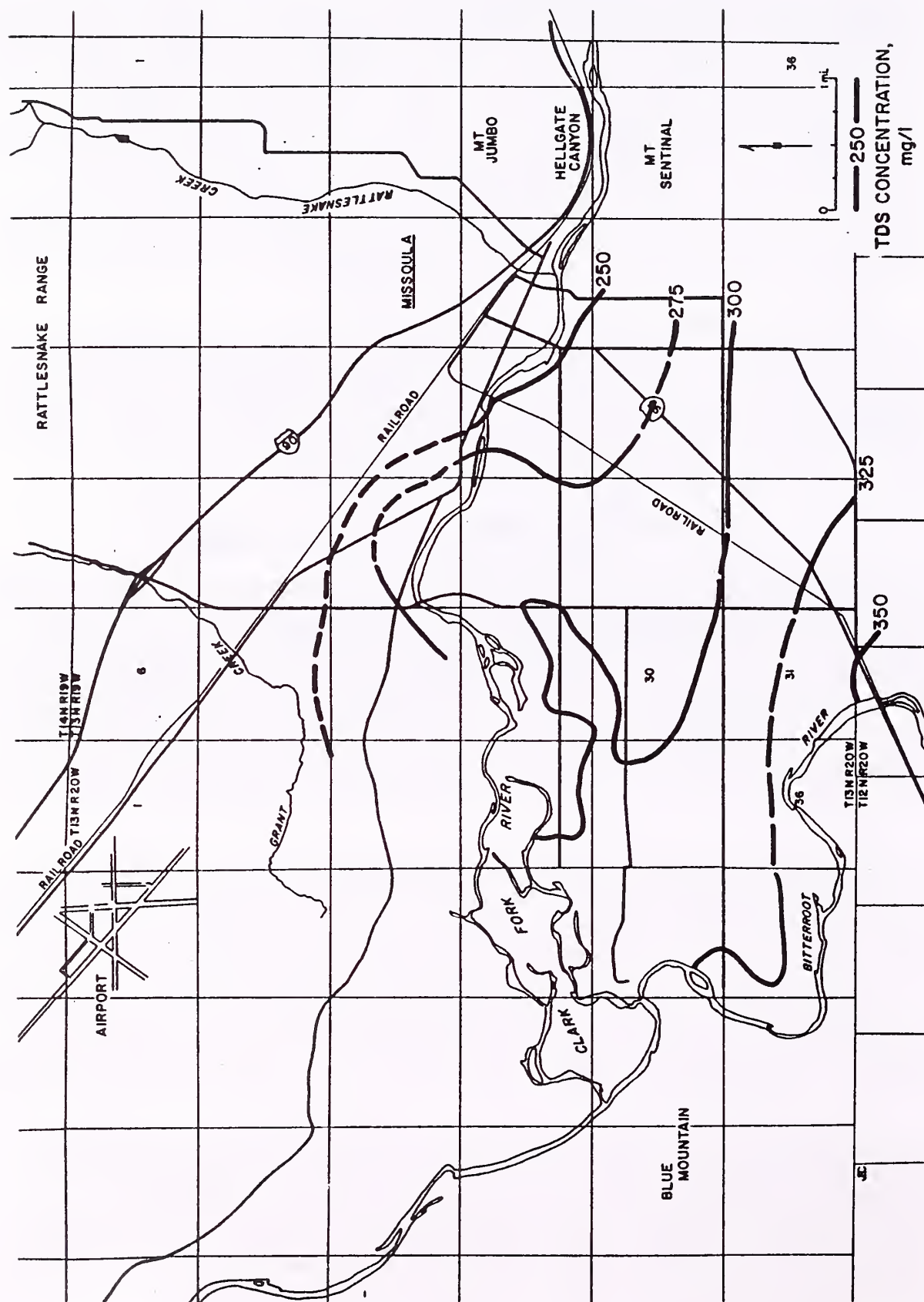


Figure 6.5: Distribution of total dissolved solids, spring 1987.

Chloride concentrations in ground water are of interest because of the potential impact on water quality from road salting and septic tank drain fields. Average chloride concentration is 3.85 mg/l (Table 6.2) and, as found for total dissolved solids, the general trend is an increase in concentration in the down gradient direction (Figure 6.6). Elevated concentrations occur in several places. Two zones of higher chloride concentration appear north of the Clark Fork River. One area is near the Russell Street Bridge and the other is associated with well MWC30 (Figure 4.1). Both are probably restricted to the north side of the river by the hydrologic divide created by recharge from the river. The source of higher chlorides north of the river is not known at this time. South of the river elevated concentrations of chloride are found in near the Champion Mill and California Street. Septic systems are the probable cause of part of the elevated chlorides found in this area. A third area with elevated chlorides is located in the southern most portion of the area between the Bitterroot River and well MWC14. In all sampling periods well MWC14 had chloride concentrations of 10 to 12 mg/l, levels which are about three times the average (Table 6.2). The higher chloride could be originating from sewage disposal by household septic systems or from natural recharge from the Tertiary sediments to the south. The final area of elevated chloride is in the western part of the valley, where some concentrations about 25% above background were found. The sources of excess chloride are most likely septic systems in areas which are not served by the city sewer system (Ver Hey, 1987).

Nitrate concentrations exceeding 2.0 mg/l were not detected in the wells sampled as part of this study. Generally, nitrate concentrations increase in the down gradient direction (Figure 6.7). Areas of apparent elevated nitrates correspond with areas of elevated chloride. Based on the available data set, the western portion of the aquifer has large areas with nitrate concentrations between 0.8 and 2 mg/l. There are no known natural sources of nitrate in the aquifer which can account for the levels found. It was originally thought that storm water injection by over 2,000 storm drains in the urban area may be loading nitrate into the system. However, Wogslund (1988) concluded that storm water injection did not appear to be adding to nitrate to the system. Ver Hey (1987) concluded, from a study of the affects of septic systems on the ground water in the western portion of the aquifer, that ground water contamination from both chloride and nitrate was occurring. Though this study did not detect concentration over about 2.0 mg/l, other researchers have found high concentrations of nitrate associated with some individual wells in the western portion of the aquifer and in subdivisions in the southwestern portion of the valley (Howard Newman, personal comm., 1988).

Sixty-six wells were sampled for dissolved trace metal concentrations. All concentrations were below EPA drinking water standards (Appendix 5B). Most concentrations were below instrument detection limits.

Water samples collected during the spring 1987 sampling period were analyzed for coliform bacteria (Figure 6.8). Eighteen out of the 98 water samples tested positive for bacteria. All but one of the positive samples came from wells west of Reserve Street. The one positive sample east of Reserve Street came from observation well MV34, which was never disinfected after completion and has not been used for water supply.

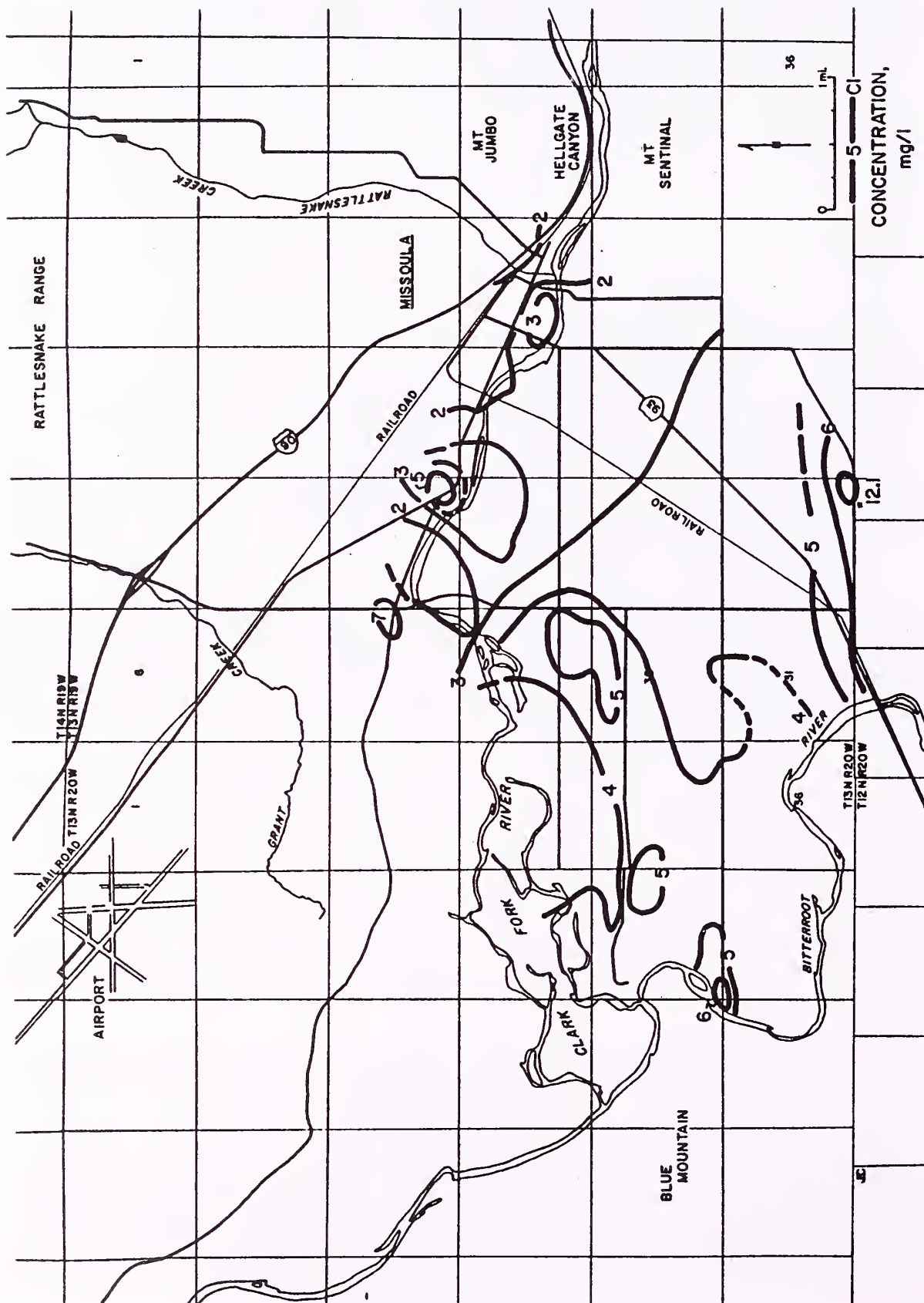


Figure 6.6: Distribution of chloride, spring 1987.

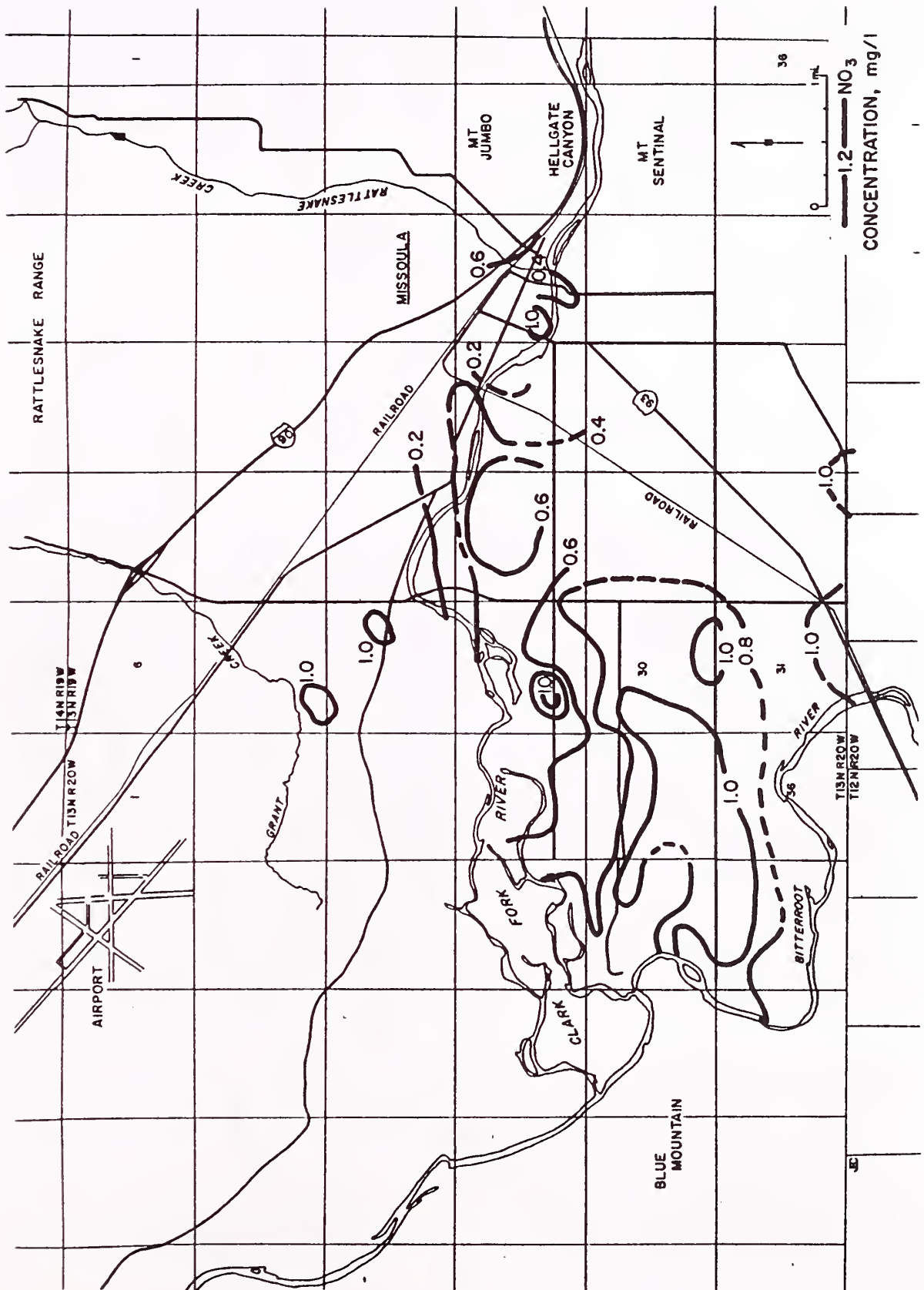


Figure 6.7: Distribution of nitrate, spring 1987.

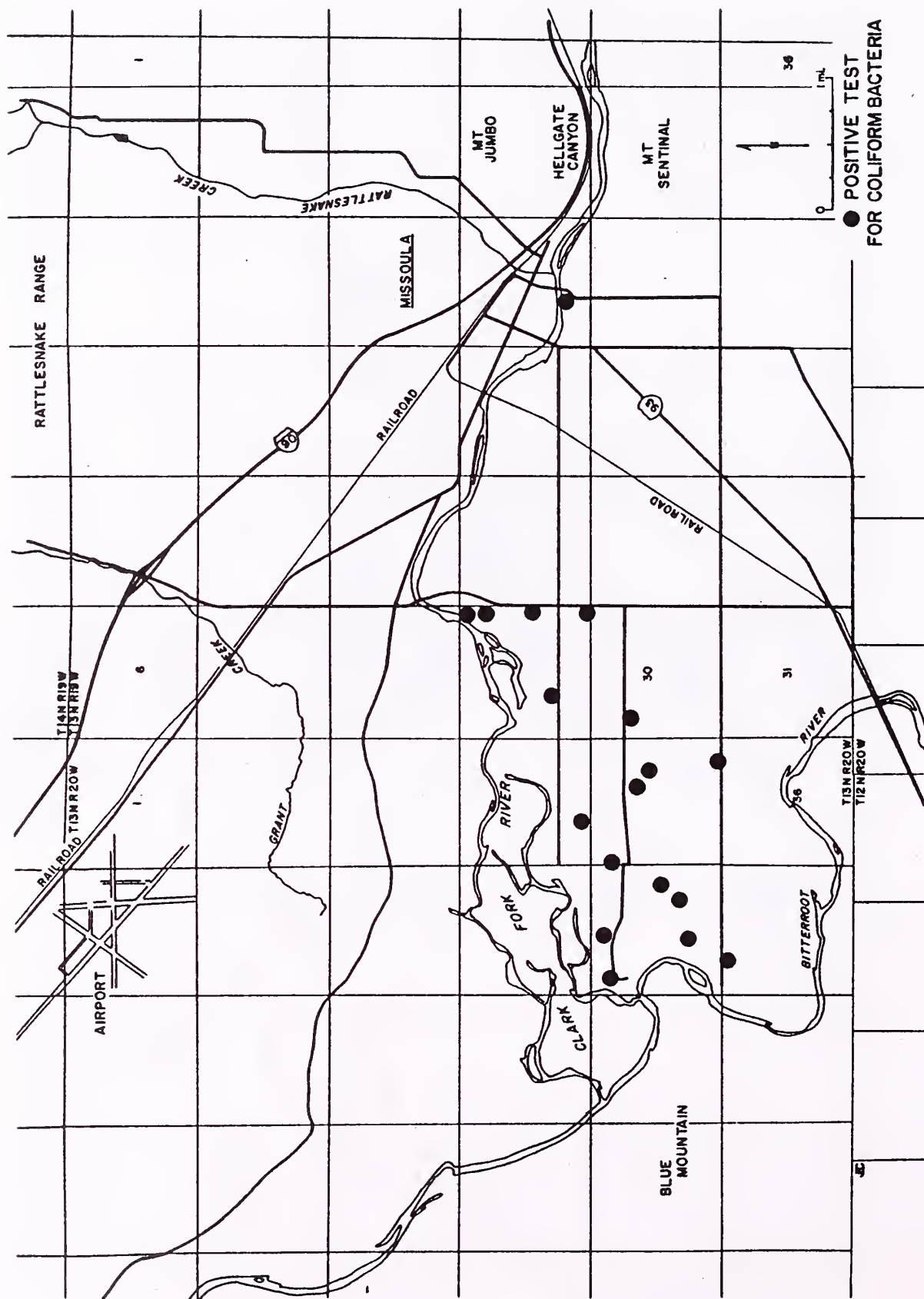


Figure 6.8: Location of positive coliform bacteria tests, spring 1987.

EPA priority pollutant scans were completed on samples from six wells (Appendix 6C). In the 112 analyses performed on each sample, all constituents were below the instrument detection limit with the few exceptions listed in Table 6.3. All detectable concentrations are lower than recommended drinking water standards. The PVC casing in wells MV41 and MV42 probably caused the contamination found in these wells. The origin of the methylene chloride (a common laboratory solvent) in two of the samples is unknown.

TABLE 6.3
Results of EPA Priority Pollutant Scans

Well	Compound above detection limit	Concentration (ug/l)
MV34	none	
MV42	bis (2-ethylhexyl) phthalate	40
#41	bis (2-ethylhexyl) phthalate	80
#28	none	
#33	methylene chloride	22
#60	methylene chloride	20

EXAMPLES OF GROUND WATER CONTAMINATION

This section illustrates the vulnerability of the Missoula Aquifer to contamination by spills, leaks and area wide percolation of water from a number of small sources. Brief summaries of research on a herbicide release, the storm drainage system and septic tanks are presented.

A. Herbicide Release

In the fall of 1984, the Montana Department of Agriculture discovered trace amounts of picloram (0.052 ug/l) and 2,4-D (0.9 ug/l) in a well serving the Missoula County Weed Control Facility (MCWCF) (Figure 6.9). They also found picloram (2.4 to 4.5 ug/l) in two wells serving a commercial trailer court and campground. The most likely source of these herbicides was the MCWCF waste sump, which was found to be contaminated with picloram, bromacil, 2,4-D and 2,4,5-TP (Figure 6.10). Herbicides were also found in the soils around and beneath the sump drain. The Montana Water Quality Bureau determined that the herbicide levels found in area wells were orders of magnitude lower than available drinking water standards but still recommended additional analysis of the site.

Pottinger (1988) assessed the ground water flow system and the transport of herbicides from the MCWCF during 1985 and 1986. He found that picloram and bromacil were the only herbicides found in measurable concentrations in an area covering over one and one half square miles (Figure 6.11). The distribution of the contaminants was controlled by water table variations of over 20 ft and by a seasonal shift in the ground water flow direction from south in the spring and early summer to southwest by west in midwinter. These changes in the ground water system are caused by seasonal variations in

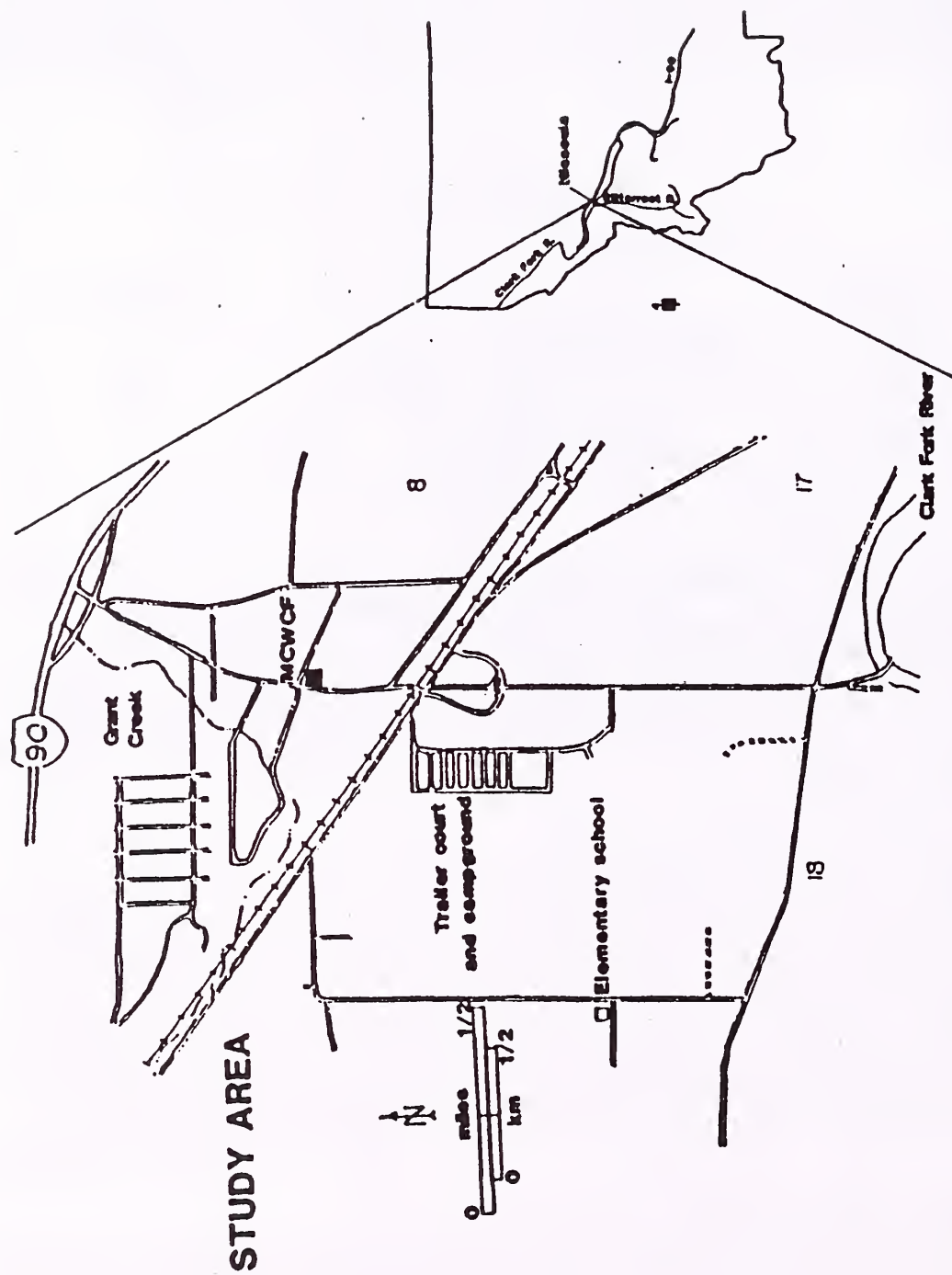


Figure 6.9: Location map for the herbicide study at the Missoula County Weed Control Facility (Pottinger, 1988).

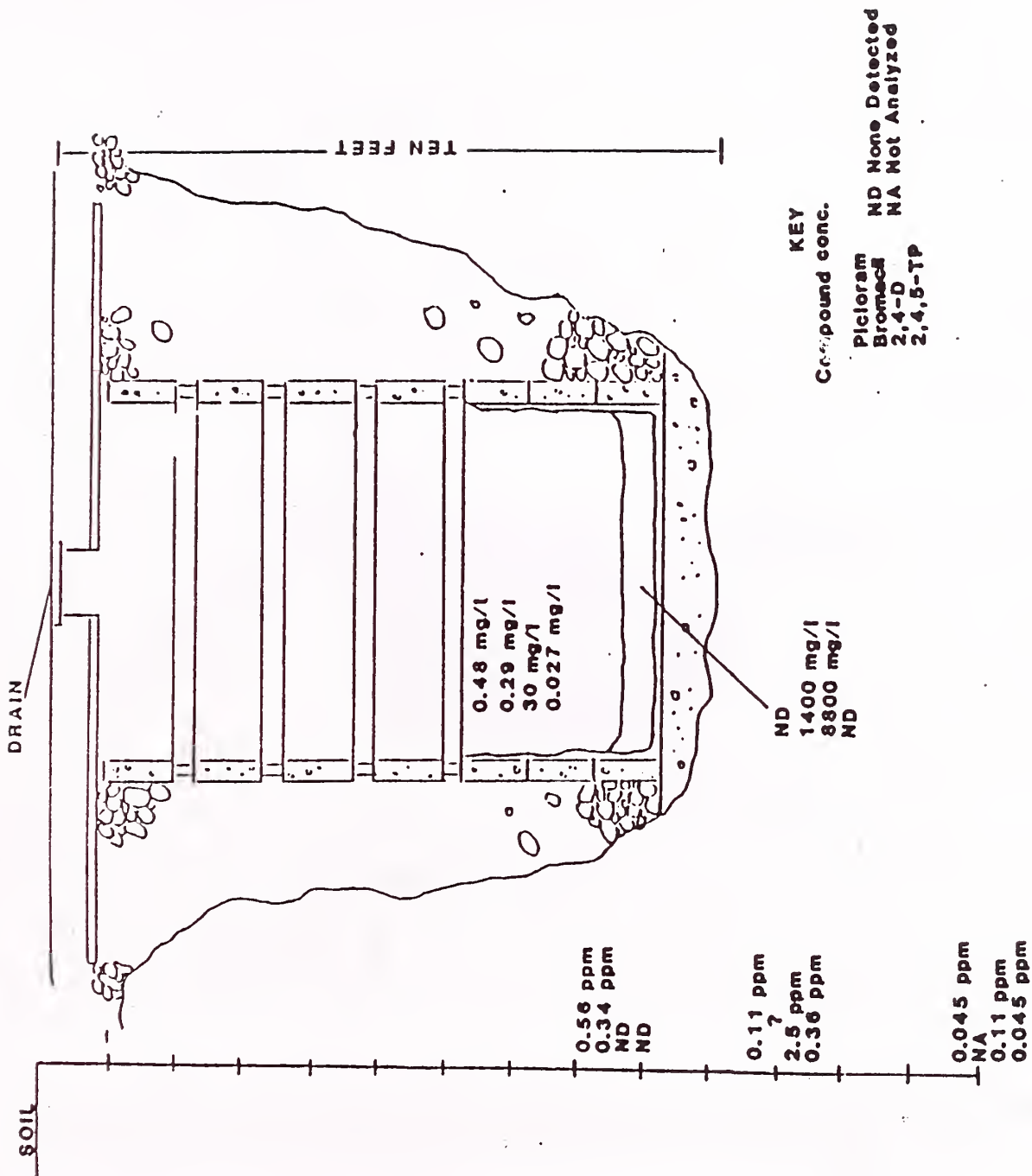


Figure 6.10: Schematic diagram of sump at Missoula County Weed Control Facility and results of water quality and soil chemical analyses (Pottinger, 1988).

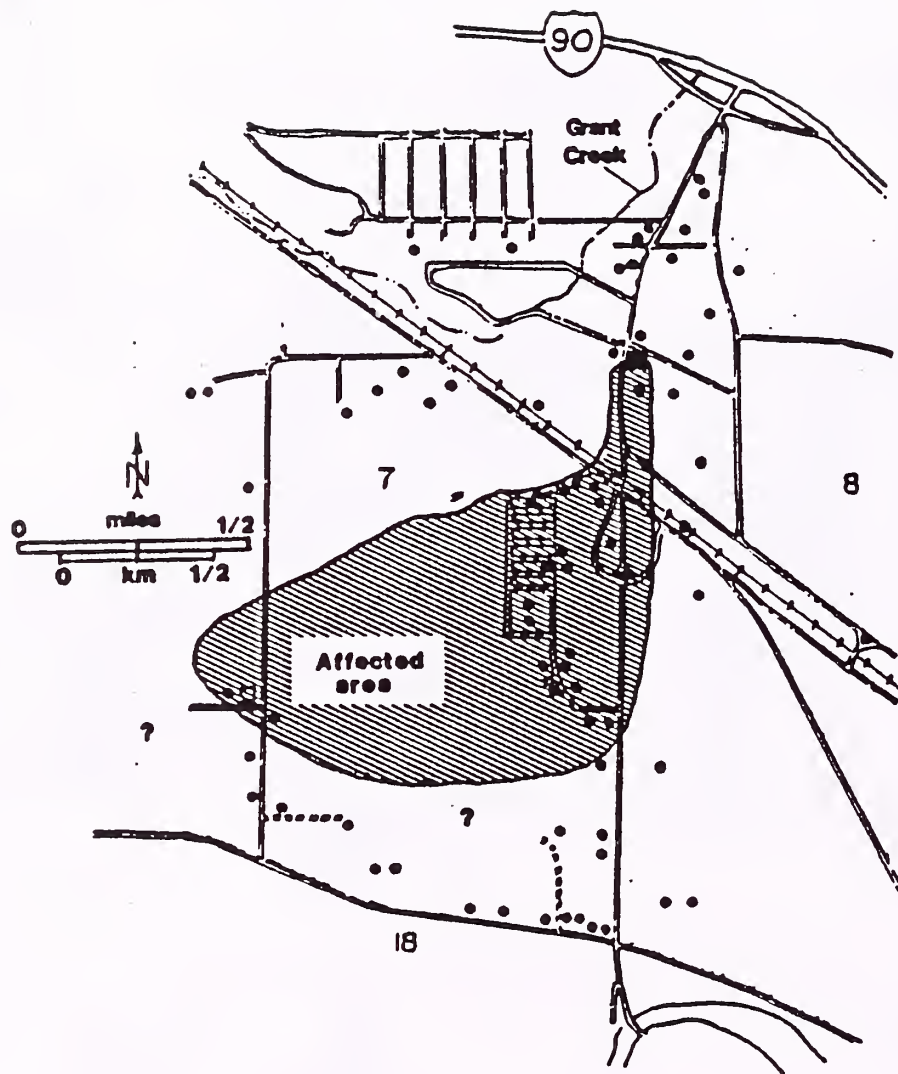


Figure 6.11: General area in which measurable concentrations of picloram and bromacil were detected in the ground water (Pottinger, 1988).

discharge to the Missoula Aquifer from the Grant Creek Valley and from Grant Creek as it flows into the valley over the Missoula Aquifer. Pottinger (1988) successfully constructed a numerical ground water flow model accounting for seasonal variation in recharge and developed a solute transport model to predict the migration of the herbicides. Figures 6.12 and 6.13 show the modeled position of the herbicide contaminated ground water in 1974 and 1989.

In summary, Pottinger (1988) demonstrated that contaminating the aquifer at one small point (less than 100 ft^2 in size) resulted in the spreading of the contaminant over 1.5 mi^2 . His work also showed that small portions of the aquifer could be successfully modeled.

B. Storm Drain Recharge

Missoula has no valley wide storm sewer system. Instead, runoff from streets percolates directly into the aquifer from over 2,000 street corner drains. Wogsland (1988) measured the quality and quantity of urban runoff in residential and commercial areas in the valley and then, using two sites instrumented with soil water and ground water sampling devices, examined the impact of storm water disposal on aquifer water quality (Figure 6.14).

Wogsland (1988) found that, with the exception of runoff from spring snowmelt, street runoff entering the aquifer is low in total dissolved solids and free of EPA priority pollutants. Commercial areas, however, do generate runoff with water quality that is worse than that from residential areas. As the water migrates through the vadose zone and towards the aquifer, it reacts with earth materials and increases in mineral content (Figure 6.15). Runoff from snowmelt contains higher total dissolved solids and sodium chloride than runoff from other sources. These higher concentrations appear to diminish as the water passes downward through the vadose zone. Figure 6.16 shows the impact of the contaminated snowmelt runoff on ground water quality directly beneath instrumented drains in a residential and a commercial area. The chloride concentration at the commercial site exceeds background by over four times during recharge by snowmelt. The data also show that the concentration of iron in the ground water is usually below detection except when chloride rich snowmelt waters reach the water table (Figure 6.17). This implies chlorides may be facilitating the transport of metals in runoff and in the vadose zone to the aquifer. Figure (6.18) shows the variation in nitrate concentration in the ground water at the commercial site. The variations in nitrate levels do not appear to be correlated with storm water injection but appear to vary in response to changes in the regional flow system.

Wogsland (1988) also sampled existing wells in the commercial area between South Avenue and US 93. Though her work is not conclusive, it appears that total dissolved solids and metal concentrations are higher than background levels in this part of the aquifer.

Wogsland's (1988) research documents the importance of snowmelt runoff and dissolution of vadose zone materials in determining the water quality in the aquifer. She concluded that the vadose zone supplies major ions to the aquifer and attenuates metal migration except during spring snowmelt recharge. Further installation of sump storm drains will contribute to minor aquifer

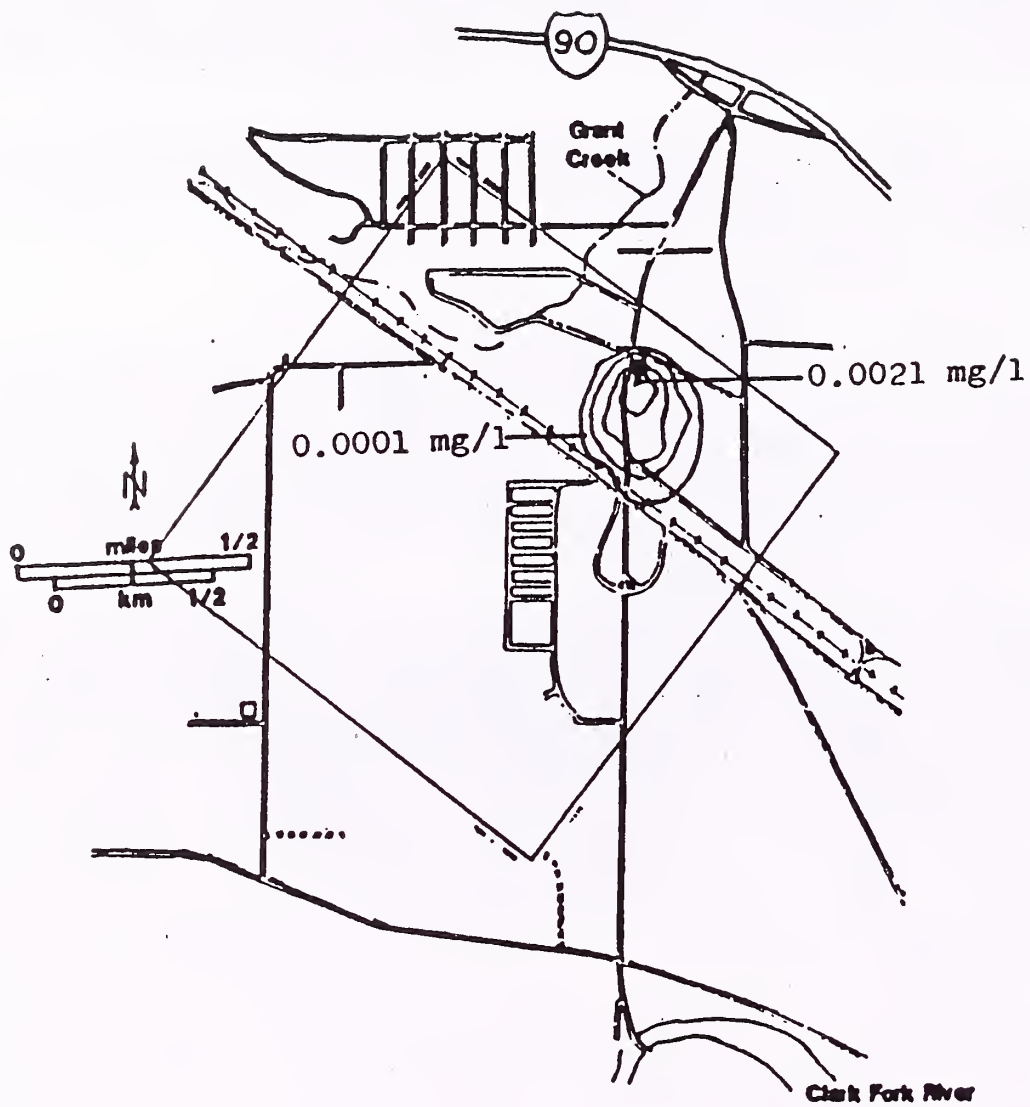


Figure 6.12: Modeled distribution of herbicides in 1974 (Pottinger, 1988).

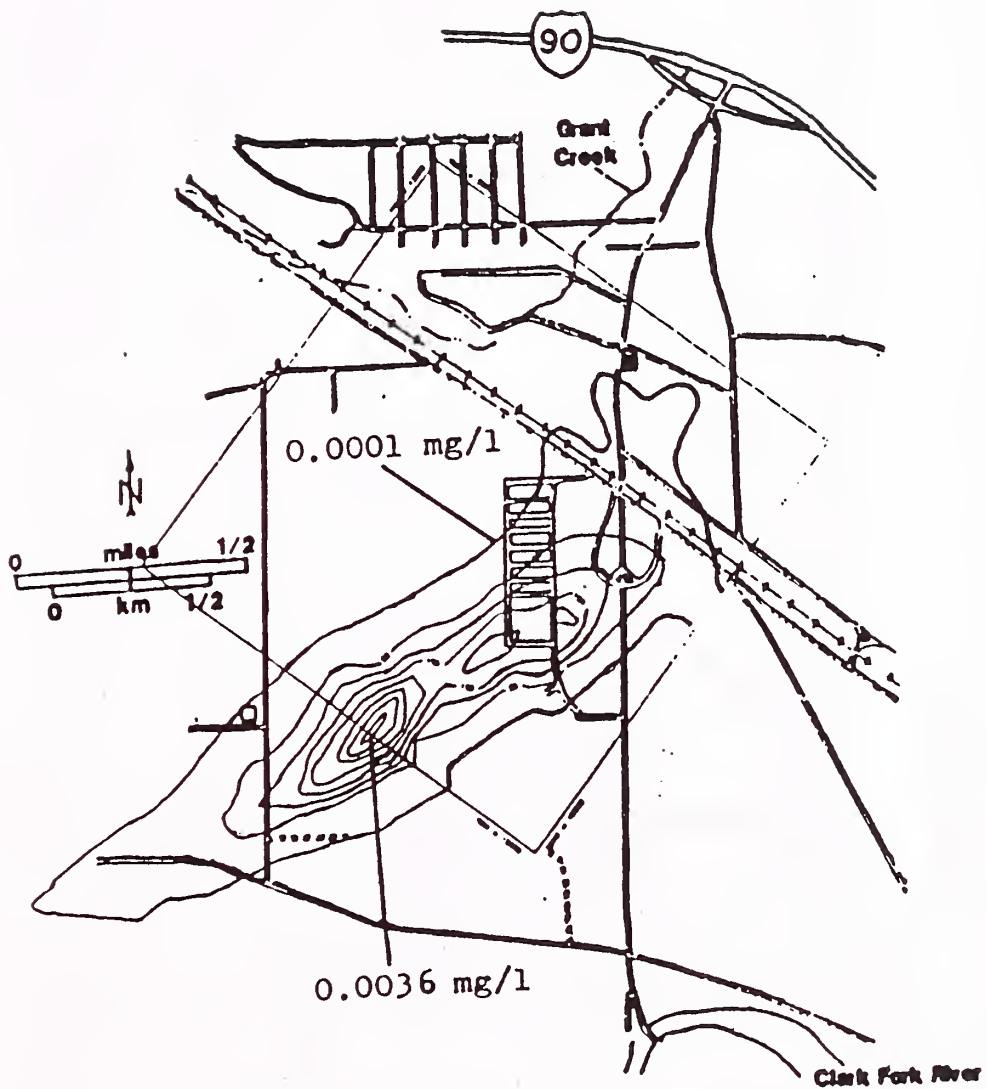


Figure 6.13: Modeled distribution of herbicides in 1989 (Pottinger, 1988).

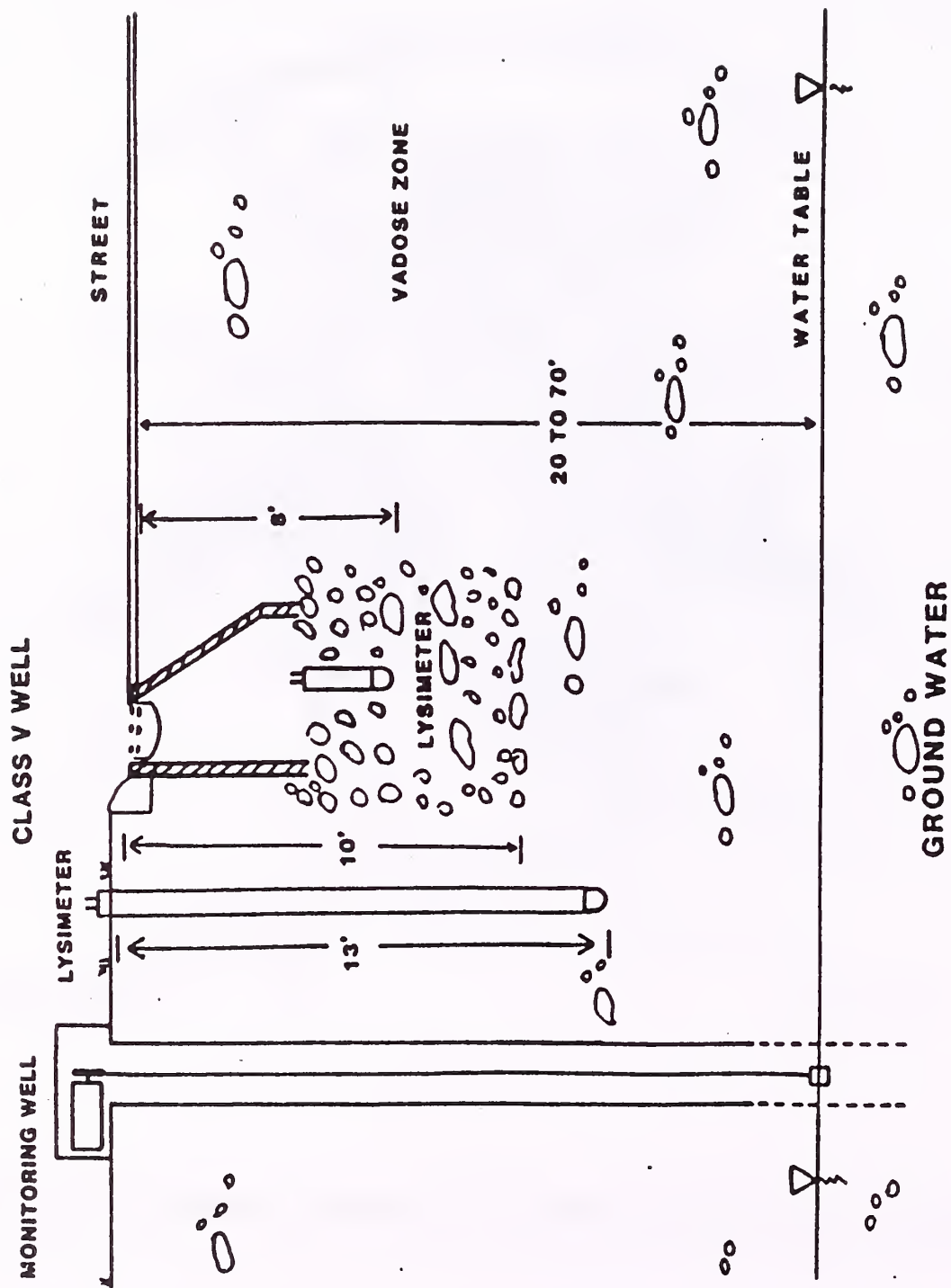


Figure 6.14: Schematic diagram of a Missoula storm drain and hydrogeologic instrumentation (Wogslund, 1988).

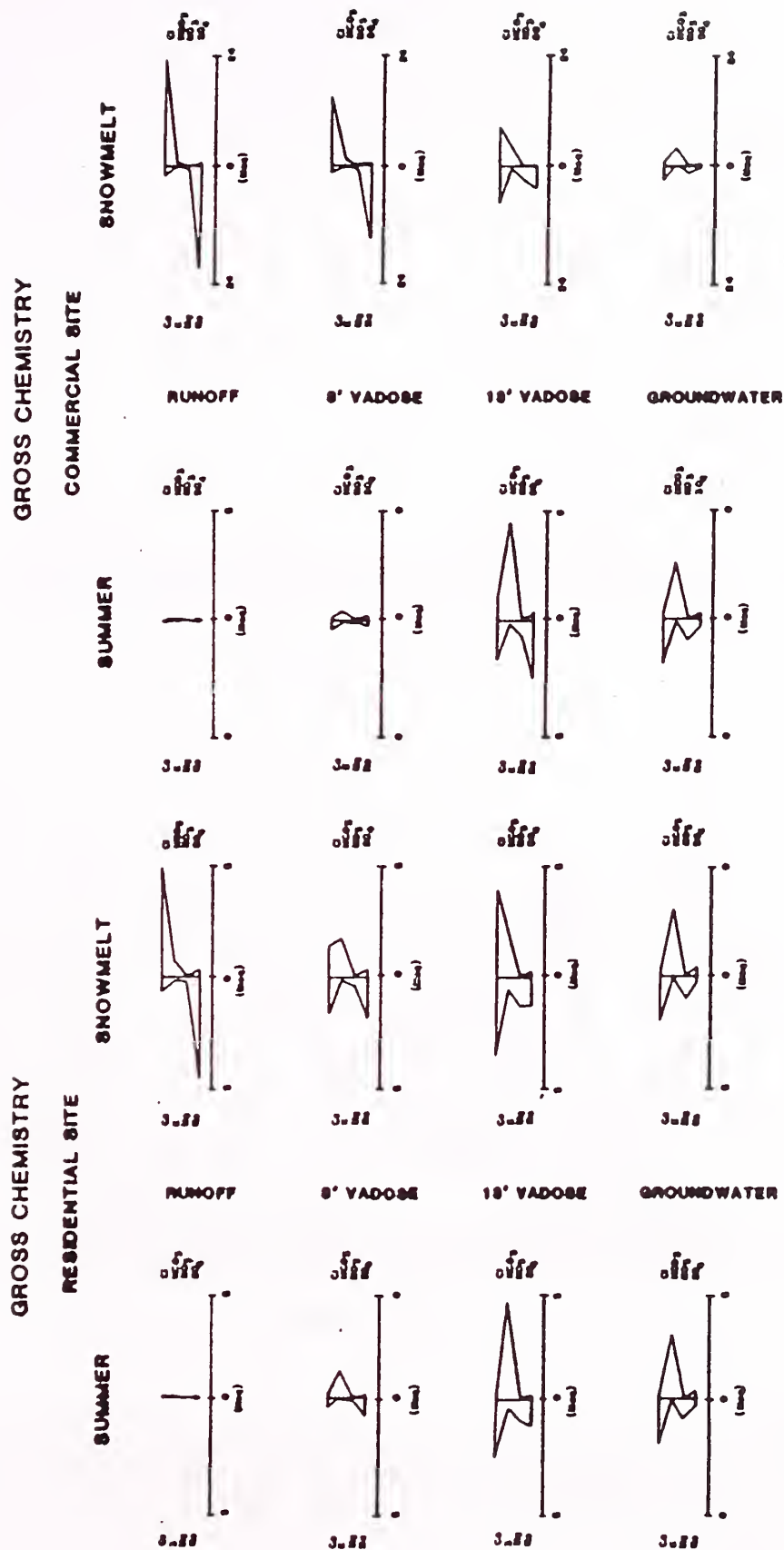


Figure 6.15: A comparison of water quality data from runoff, vadose water and ground water at a residential and a commercial storm drain site (Wogsland, 1988).

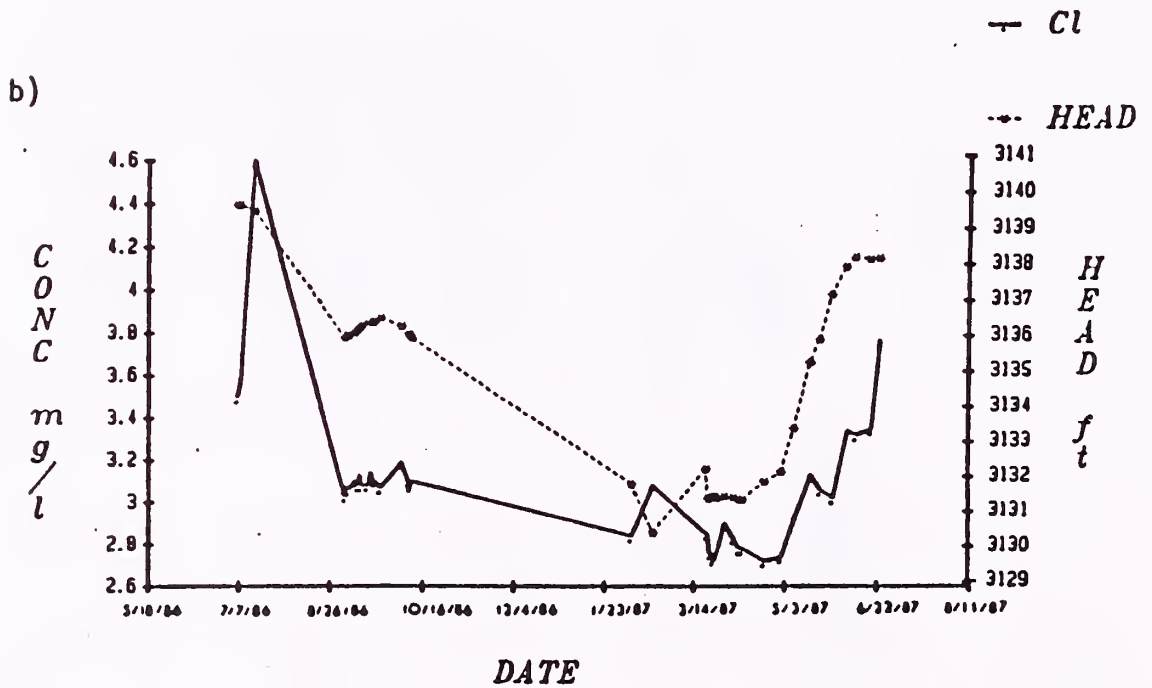
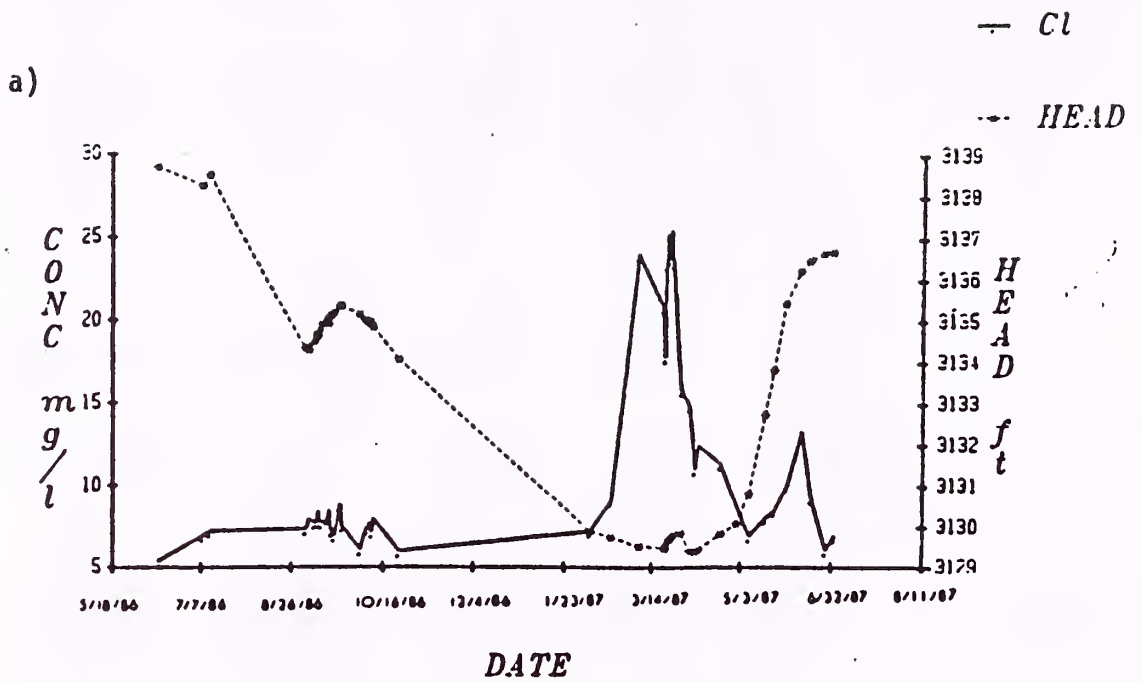


Figure 6.16: Chloride concentration and water table fluctuations versus time for a commercial site and residential site (Wogsland, 1988).

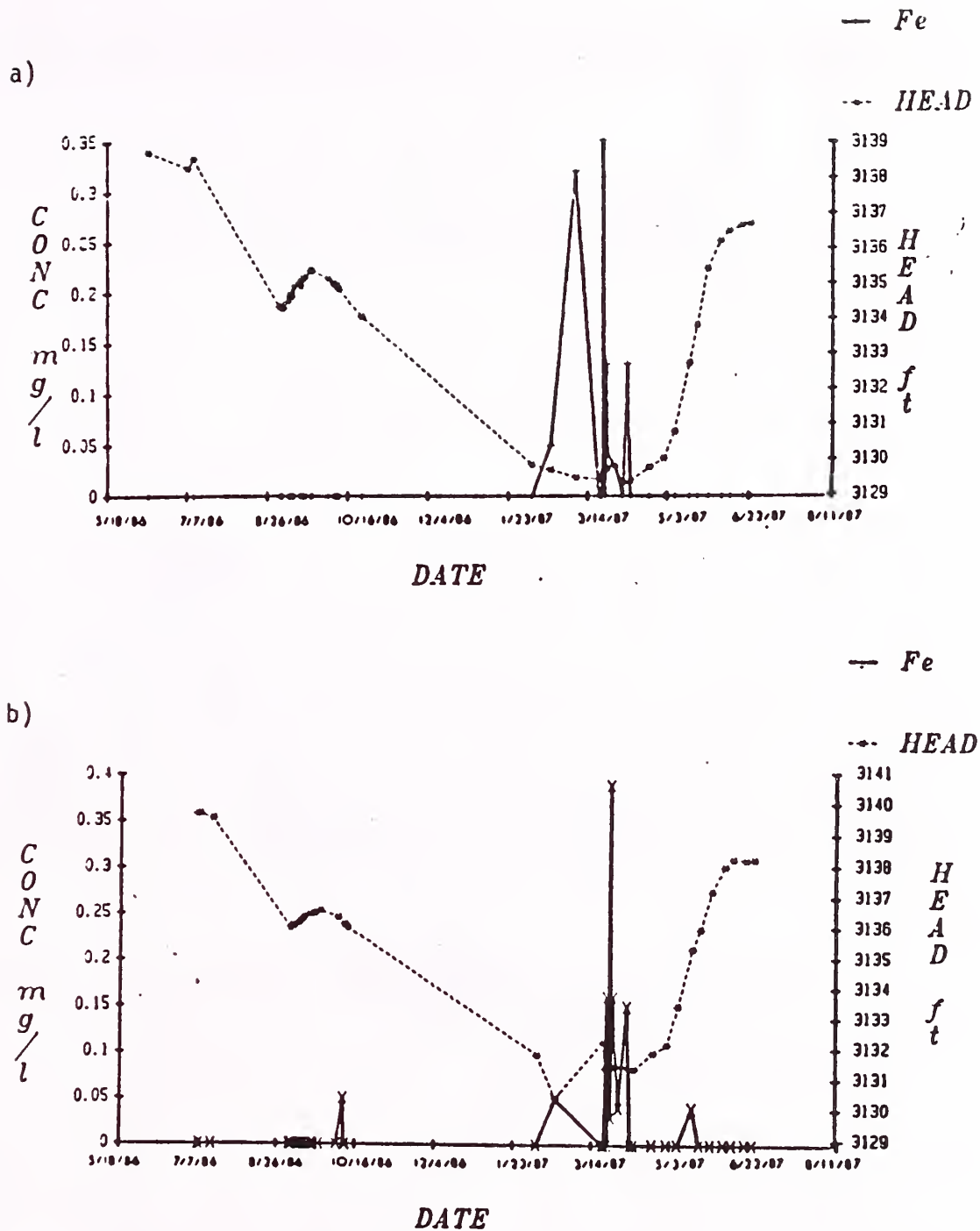


Figure 6.17: Iron concentration and water table fluctuations versus time at a commercial site and a residential (Wogsland, 1988).

— NO3-N

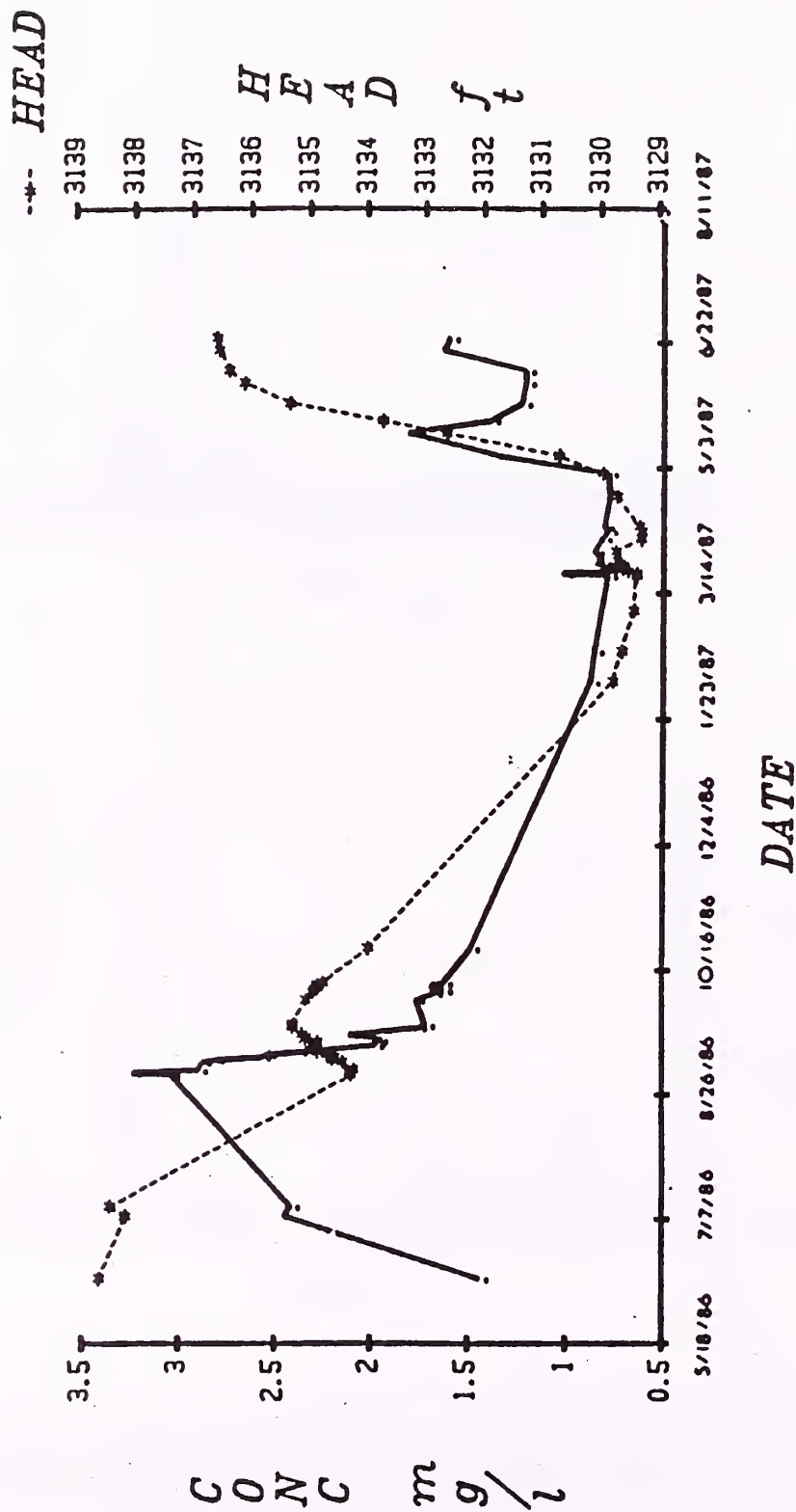


Figure 6.18: Nitrate concentration and water table fluctuations versus time at a commercial site and a residential site (Wogslund, 1988).

contamination. But, more importantly, Missoula's storm drains provide an open conduit to the aquifer for any contaminants or hazardous wastes spilled on city streets.

C. Domestic Sewage Recharge

Two household septic systems located in the western part of the valley (Figure 6.19) were instrumented and studied in 1985 and 1986 by Ver Hey (1987). An access port was installed in each septic tank and soil water samplers were installed at two depths in the vadose zone below the drain field. Water meters were used to determine the rate at which waste entered the septic system. Wells were used to sample the quality of the underlying ground water (Figure 6.20). Both sites were located in coarse soils classified as Grantsdale loam. All legal requirements for septic system installation had been met at each site. The water table varied seasonally between 8.5 and 14 ft below land surface.

The study showed that the septic drain fields are relatively ineffective in treating household effluent due to the coarse grained soils in which the systems were installed (Table 6.4). Approximately 200 gallons per day per household enter each system, but the water retention time in the coarse soils is so short that all effluent percolates out of the drain field within 15 ft of the septic tank. Also no biological mat was found during excavation of the drain fields. Water analyses show that no statistically significant reduction in phosphorus or nitrogen concentrations occurs as the effluent percolates from the drain field to the water table. A plume of nitrate and chloride could be traced down gradient from the drain field at both sites (Figure 6.21 and 6.22). Fecal coliform numbers were above the maximum detectable limit in ground water samples taken directly below the drain field and were still high (eight bacteria per 100 ml) 50 ft down gradient (Figure 6.23). The presence

TABLE 6.4
Septic System Treatment as Mean Per Cent Removal of Effluent
Constituents, Year Two (Ver Hey, 1987)

	Specific Conductance	Total Nitrogen	Ortho- Phosphate	Sodium	Chloride
<u>Site H</u>					
Septic System	nt*	nt	nt	nt	57
Vadose Zone	22	32	nt	nt	-21
Aquifer	32	nt	79	nt	nt
<u>Site T</u>					
Septic System	nt	35	nt	nt	45
Vadose Zone	nt	nt	nt	nt	nt
Aquifer	nt	41	46	nt	nt

(* nt = no statistically significant change in the means)

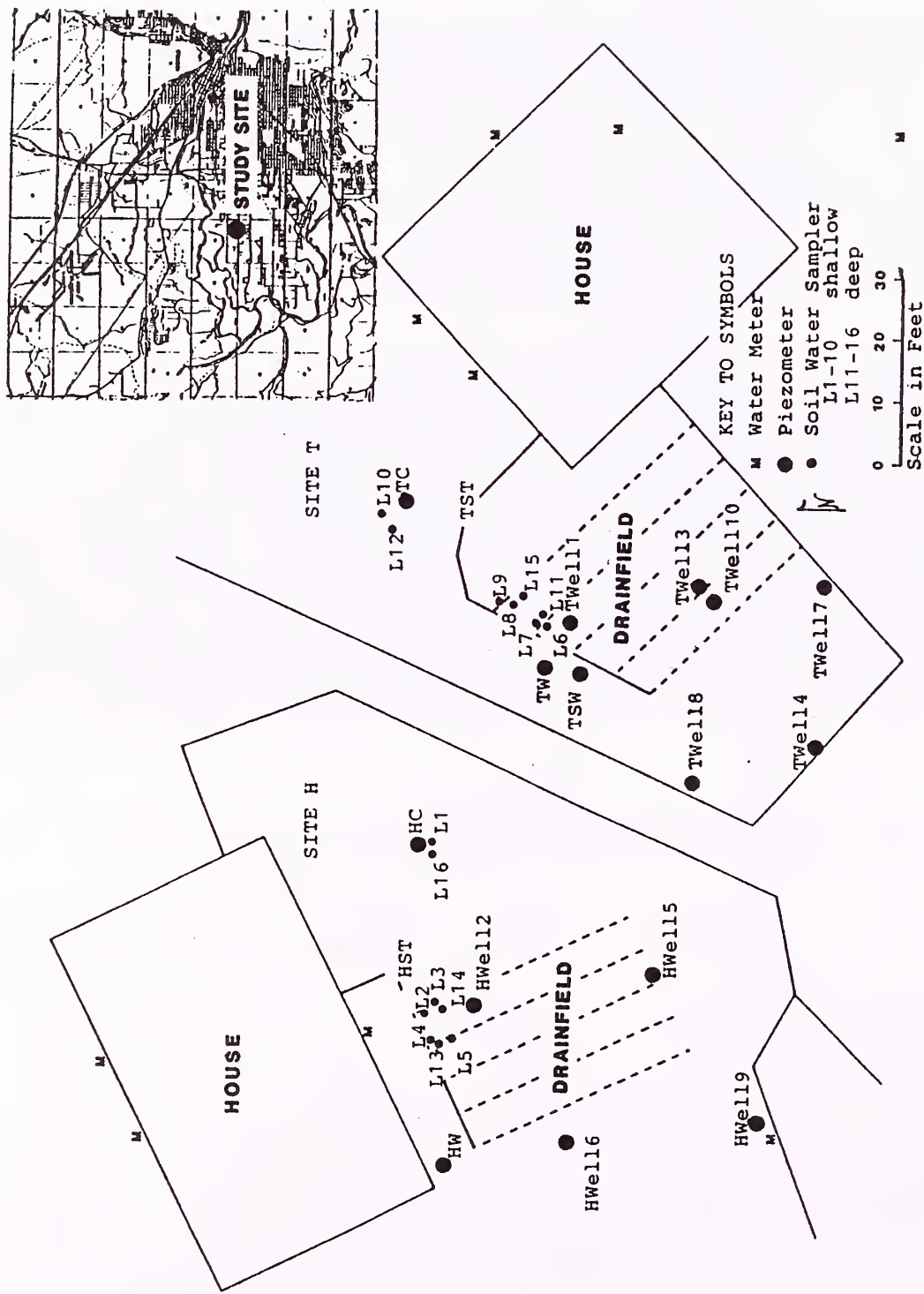


Figure 6.19: Location and instrumentation of septic system study sites (after Ver Hey, 1987).

INSTRUMENTATION

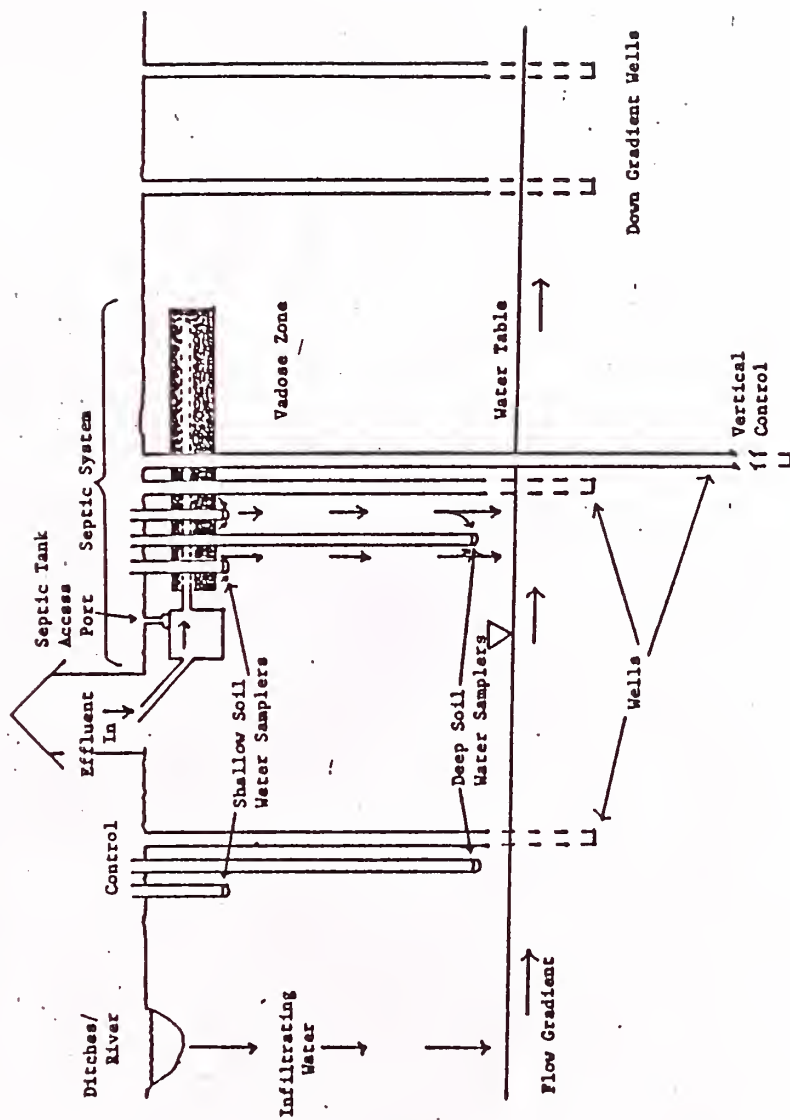


Figure 6.20: Schematic diagram of hydrologic instrumentation at each site (Ver Hey, 1987).

CHLORIDE PLUMES

HOUSE

HOUSE

Site M

Site T

HOUSE

1964-1986
Missouri Valley Gas-ole
Seismic System Study

KEY TO SYMBOLS

Water Meter
Well
Soil Water Sampler
L1-76 Shallow
L1-16 Deep

CONCENTRATION, mg/l

0 10 20 30

Scale in Feet

100

[illegible]

101

FECAL COLIFORM

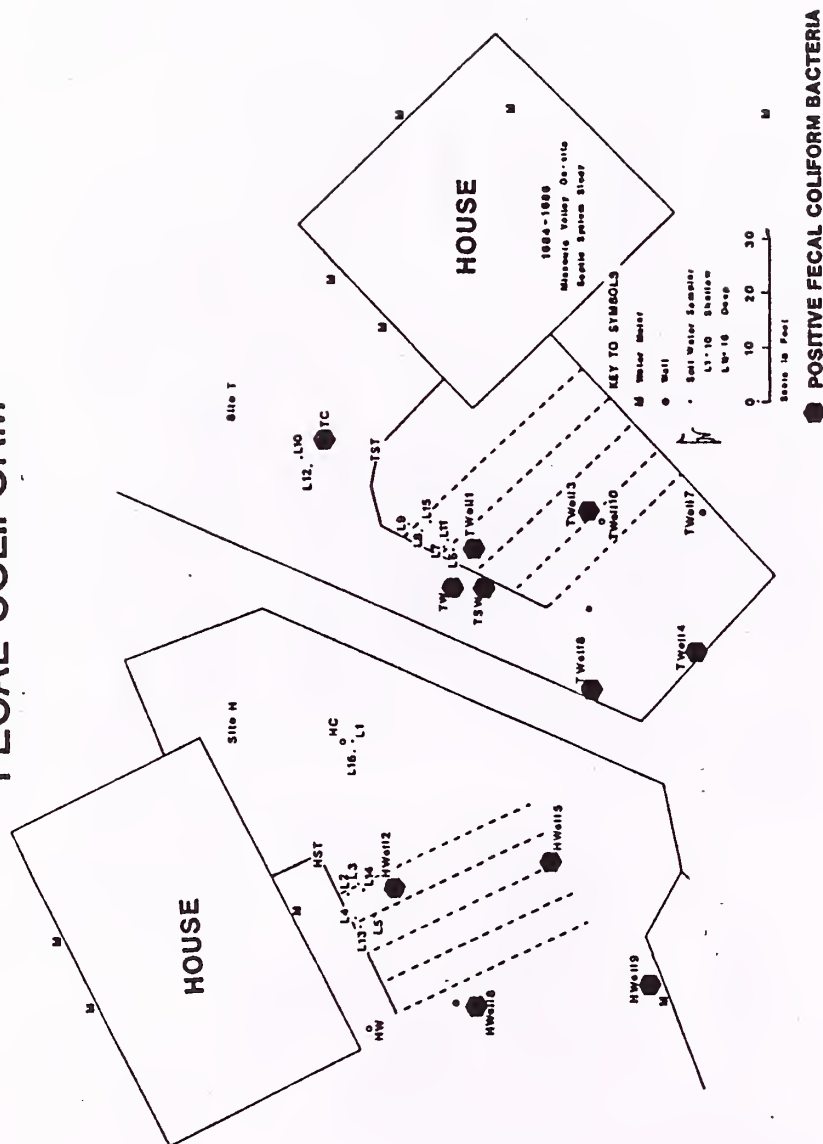


Figure 6.23: Location of ground water samples contaminated with fecal coliform bacteria (after Ver Hey, 1987).

of a 0.2 inch amphipod in a ground water sample suggests that void spaces are large in the underlying aquifer. Samples of ground water taken up gradient of the study site have elevated concentrations of chemical constituents and possibly indicate wide spread degradation of ground water quality by individual septic systems in the area.

Ver Hey (1987) concluded that traditional septic system design is ineffective in treating domestic waste in the coarse alluvial soils of the Missoula Valley. She cautioned that the continued use of existing systems and the addition of new systems would result in degradation of existing ground water supplies.

CHAPTER 7

GROUND WATER FLOW MODELING

INTRODUCTION

Construction and calibration of a transient model of ground water flow through the Missoula Aquifer proved to be a difficult task. Although significant progress was made in defining the distribution of aquifer properties and boundaries, and in understanding the interaction between the Clark Fork River and the ground water system, we were unsuccessful in developing a complete numerical model which could be used for predictive purposes. Future modeling efforts based on this work and coupled with collection of additional data will be able to describe the responses of the aquifer to variations in Clark Fork River recharge and to pumping by Mountain Water Company. The following discussion of ground water modeling is taken from unpublished work by Brick (1987).

MODEL DESIGN

A two-dimensional model was developed for ground water flow in the aquifer for one year starting in October 1985 and ending in September 1986. The area covered is shown in Figure 7.1. The finite difference computer code named PLASM developed by Prickett and Lonquist (1971) and subsequently adapted by Prickett for the IBM PC series computer was used. Several modifications were made to this program to tailor it to this study. Data for the model were taken from past and ongoing work, especially that of Clark (1986) and Pottinger (1988).

The Missoula Valley and the grid for this model are bounded by Mt. Sentinel to the east, Waterworks Hill to the north, the South Hills and Bitterroot River to the south and thick Lake Missoula sediments of low permeability to the west. The grid consists of 38 columns and 31 rows with variable node spacing. The density of nodes is greater over the population center of Missoula and the locations of municipal wells (Figures 7.1 and 7.2). The boundary conditions for the grid are illustrated in Figure 7.3. The east and west boundaries are no-flow boundaries. A constant head is assigned to a portion of the north boundary because flow maps and previous work by Geldon (1979) indicate a small source of water from the north, possibly from the Tertiary sediments. Pottinger (1988) also used a constant head boundary in this area. The model was modified to allow the constant head at the north boundary to change seasonally because a seasonal change in head is indicated by potentiometric maps of the aquifer (Figures 5.1 to 5.3). The constant head at this boundary was set to vary between 3,142 ft and 3,155 ft. The south boundary is defined by the Bitterroot River and is assigned a constant head determined by the river's stage and gradient. This boundary is discussed further below.

Apart from the model's boundaries, initial input parameters include the storage coefficient, hydraulic conductivity and the thickness of the aquifer. In each of the two modeled dimensions, the aquifer is divided into blocks

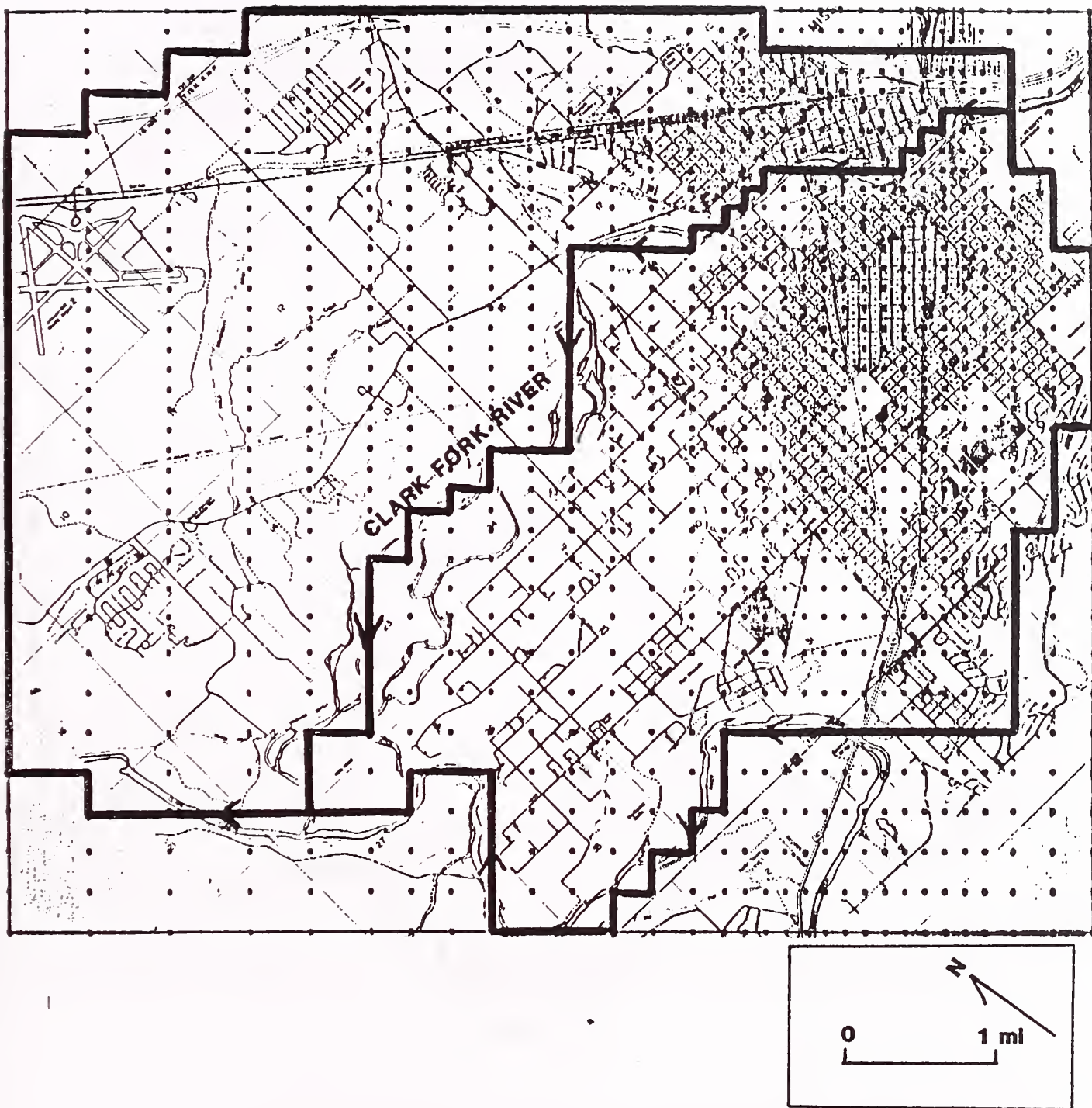


Figure 7.1: Grid for finite difference model (after Brick, 1987).

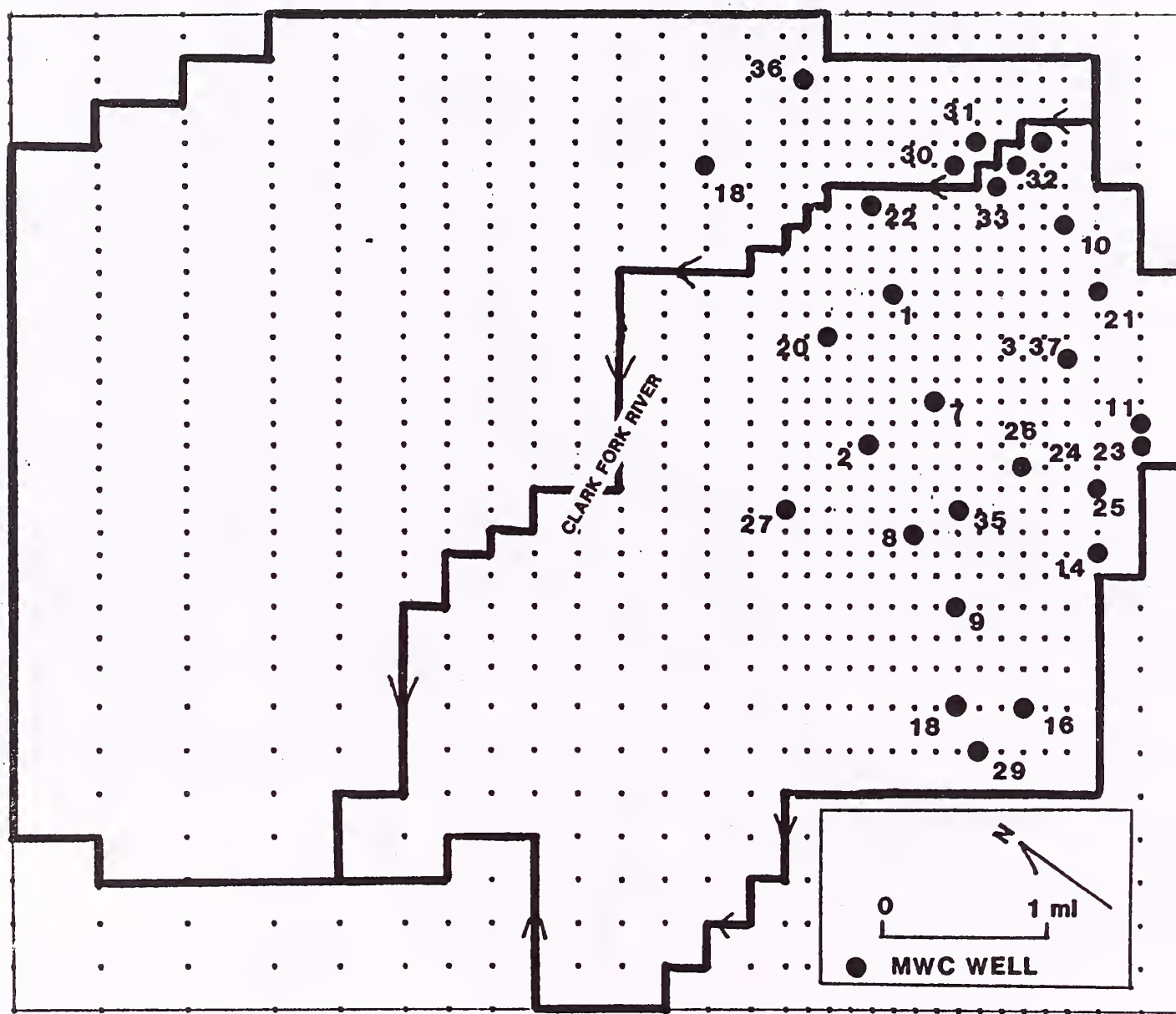


Figure 7.2: Model grid and location of Mountain Water Company wells (after Brick, 1987).

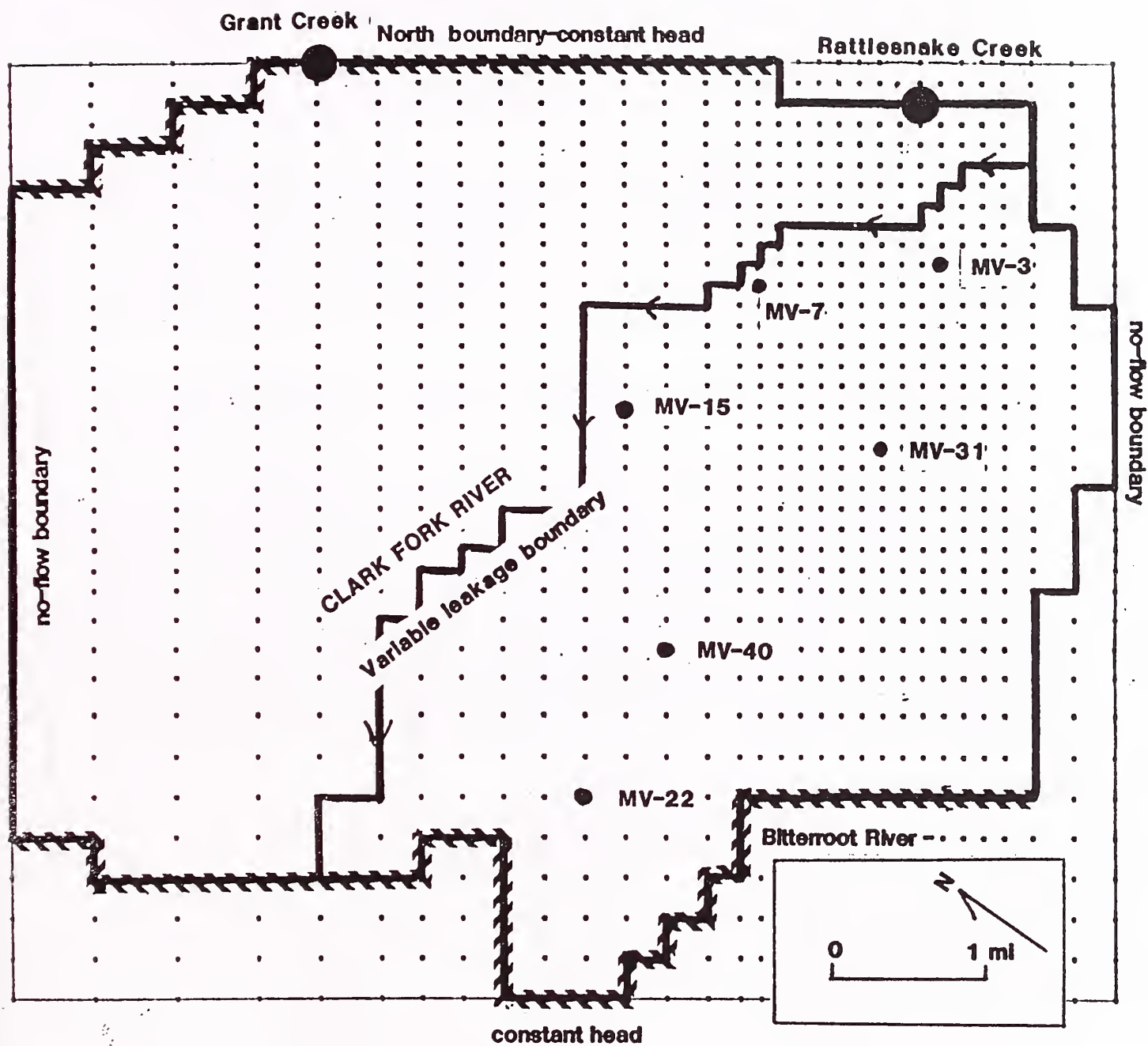


Figure 7.3: Model boundary conditions and locations of wells used to evaluate calibration (after Brick, 1987).

which are bounded by two adjacent nodes and which have constant hydraulic properties. Heterogeneity can be modeled by assigning different hydraulic conductivity and storage values to each of these blocks. Hydraulic conductivity and storage coefficient cannot vary with depth because the model is two-dimensional. The storage coefficient in this model is 0.10, which is close to the 0.12 value measured in permeameter tests and to storage coefficient values (0.03 to 0.10) determined from several aquifer tests (Clark, 1986).

The hydraulic conductivity distribution used in the model was based on previous research and Figure 3.8. The model itself was also used to evaluate hydraulic conductivity values. The final distribution of values is illustrated in Figure 7.4. It should be emphasized that this distribution of hydraulic conductivity values was chosen because the results of the model fit known steady state water level data and not because it necessarily represents reality.

The bottom elevation of the modeled aquifer is represented by the contour lines in Figure 7.5. This configuration is based on the work of Morgan (1986) and Figure 3.2.

Additional input parameters include the location and temporal variations of major water sources and sinks. These include the withdrawal from municipal wells and infiltration from streams (Clark Fork River, Rattlesnake Creek and Grant Creek). The selection of Clark Fork River recharge rates is discussed below. Rattlesnake Creek and Grant Creek are treated as injection wells where they enter the valley. The amount of water injected was determined from the work of Sendler (1986) and du Breuil (1983). Rattlesnake Creek is represented by one injection well while Grant Creek is represented by eight wells which extend into the valley. The monthly injection schedules for these wells are in Table 7.1. These sources provide a minimal amount of water except during runoff in May and June.

TABLE 7.1
Schedule of Injection Wells Used to Simulate
Rattlesnake Creek and Grant Creek
(gpd per node)

Month	Rattlesnake Creek	Grant Creek
Oct	10,000	50,000
Nov	10,000	50,000
Dec	10,000	50,000
Jan	10,000	50,000
Feb	50,000	100,000
Mar	100,000	400,000
Apr	200,000	600,000
May	300,000	900,000
Jun	400,000	900,000
Jul	100,000	200,000
Aug	10,000	100,000
Sep	10,000	200,000

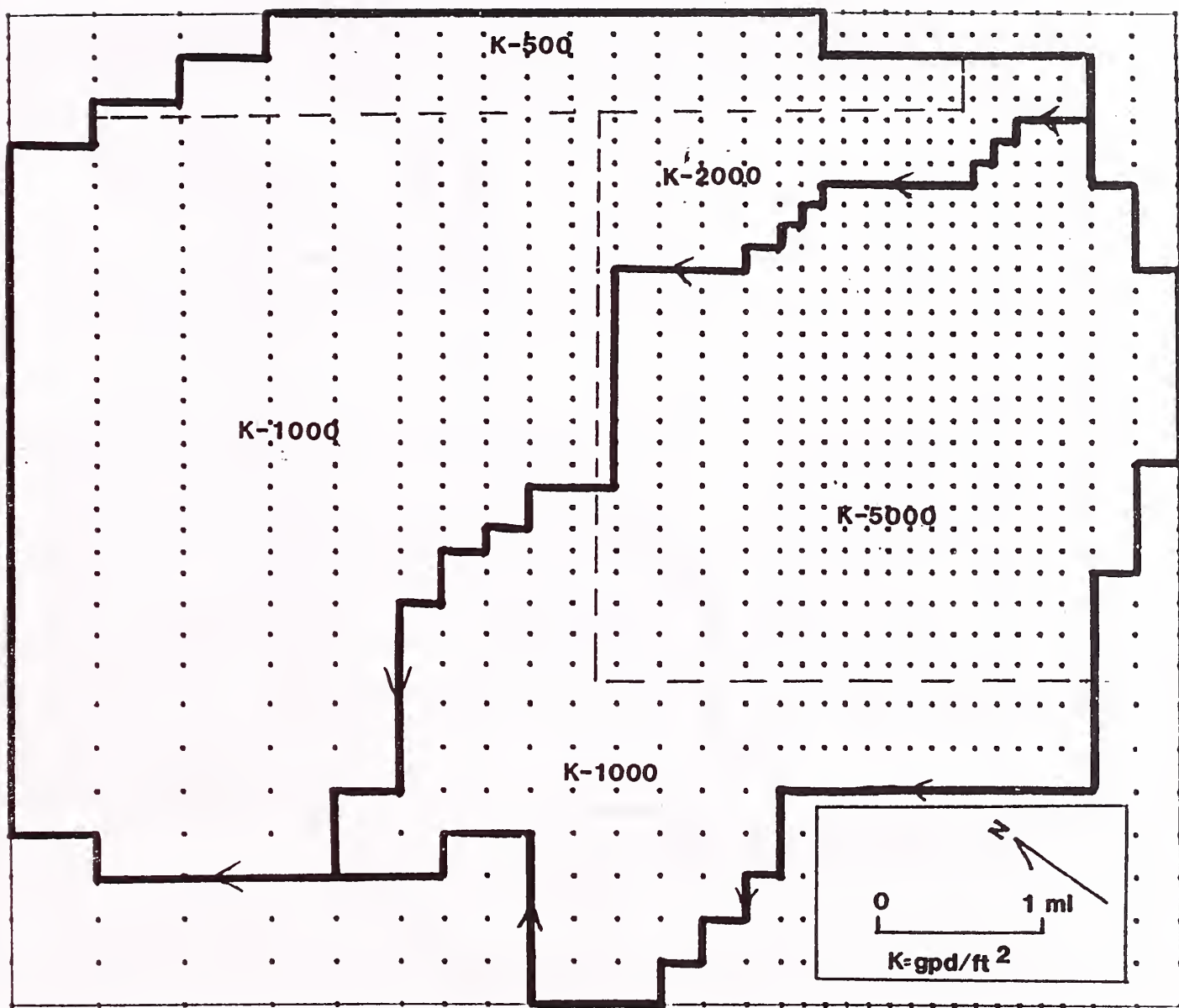


Figure 7.4: Distribution of hydraulic conductivity used in the model (after Brick, 1987).

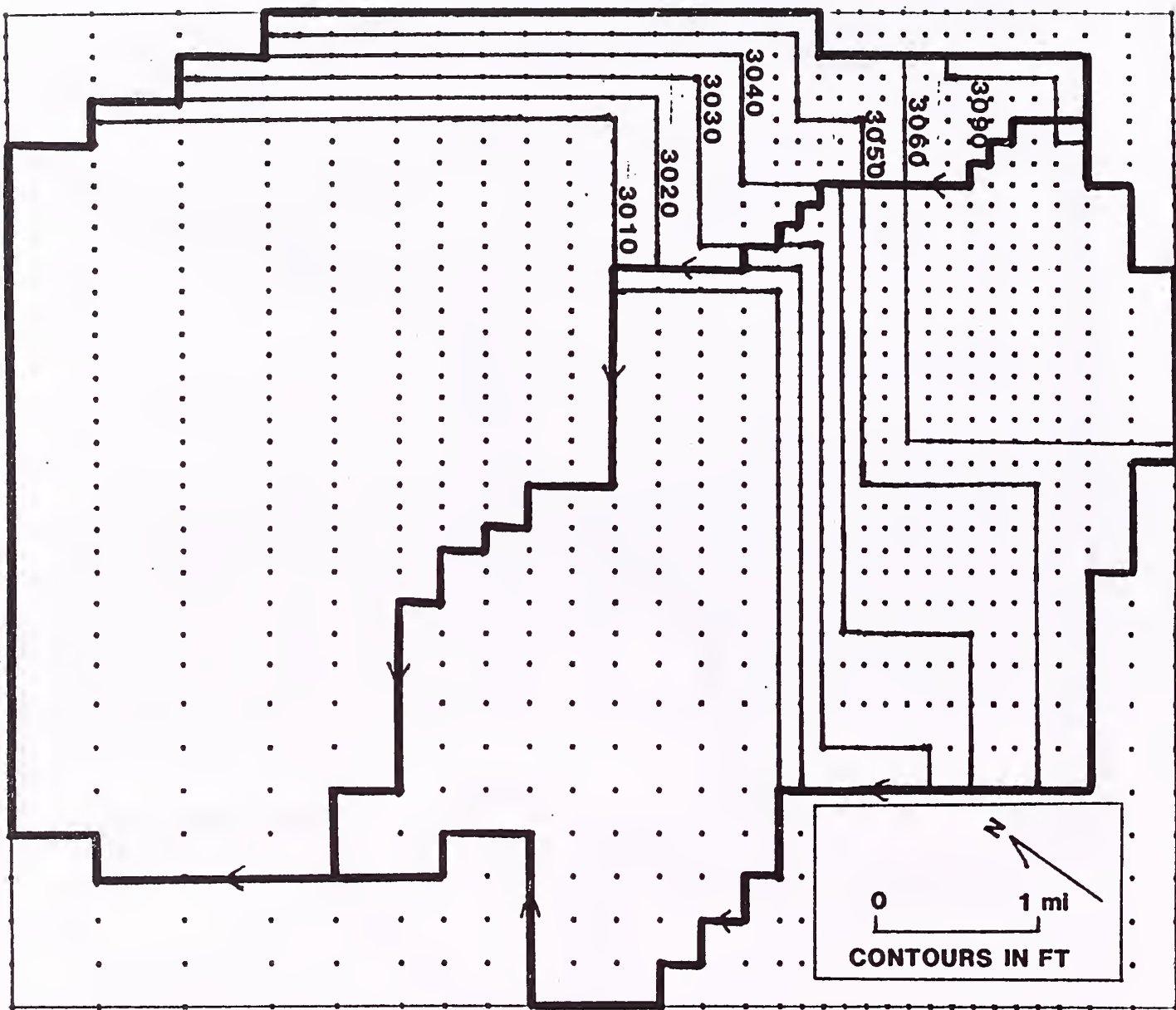


Figure 7.5: Elevations of the base of the aquifer used in the model (after Brick, 1987).

Pumping schedules for municipal wells were obtained from Mountain Water Company. The monthly production rates were converted to a daily rate and then divided in half to account for the assumed 50 percent loss by leakage from distribution lines (Table 7.2). This leakage recharges the aquifer, and, for all practical purposes, reduces pumpage by half. MWC well locations are shown on the modeling grid in Figure 7.2.

TRANSIENT FLOW SIMULATION

Downward leakage of Clark Fork River water is the main source of recharge to the Missoula Aquifer and therefore the primary driving force of the ground water flow system. The recharge rate is dependent on the stage of the river and the leakage rate through the river bed. The flow system responds less strongly to the stage of the Bitterroot River, discharge from Grant, Rattlesnake Creeks and pumping of large yield wells and variation in lateral flow from Tertiary and Precambrian bedrock which bounds the aquifer.

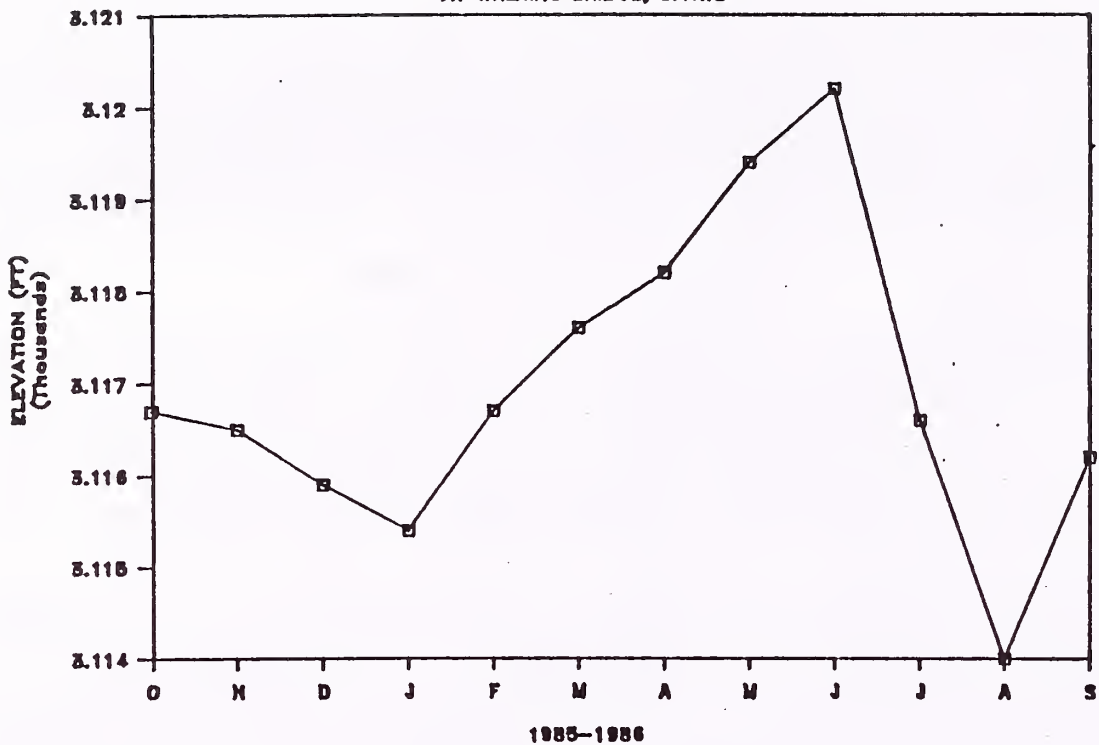
In order to model the aquifer over a one year period, it was necessary to periodically change the stage of the Clark Fork and Bitterroot Rivers and to change the leakage rate of the Clark Fork River. To accomplish these conditions, the PLASM code was modified to read new values of head (stage) and leakance each month. Average monthly discharges of the Clark Fork River were calculated from the USGS gaging data recorded at the station above Missoula (Figure 2.3). Monthly discharges of the Bitterroot River were estimated by subtracting Clark Fork River discharge measurements at the gaging stations above and below Missoula. These values compared favorably to several discharge measurements made on the Bitterroot River by Clark (1986). Discharges were converted to river depth or stage (Figure 7.6) using stage-discharge relationships developed for each river by Clark (1986). River stage elevations were then correlated with river profiles determined from USGS topographic maps.

The leakage of the Clark Fork River bed is known to vary, possibly in response to seasonal changes in the bed's permeability (Clark, 1986). Leakage was calculated from Clark's measurements of discharge lost from the river. Though estimated in Chapter 5, the average rate of leakage is not known for each month. Based on available data, leakage rates from 0 to 5 gpd/ft³ at each river node of the model were selected to initiate modeling. Since the value of leakage was not well determined, a number of different values were tested in the model. The final values used are in Table 7.3.

The transient model simulation begins in October 1985 after the model has reached steady state conditions. The steady state heads are used as initial heads for October. The model then reads new head and leakance values for the Clark Fork River, new head values for the Bitterroot River, new injection rates for wells simulating Grant Creek and Rattlesnake Creek, new discharge rates for the pumping wells, and adjustments for recharge from the northern model boundary. A new set of simulated heads is then calculated for the end of the month. This process continues for 11 months until completion of the simulation at the end of September 1986.

CLARK FORK RIVER AVERAGE MONTHLY STAGE

AT WALKING BRIDGE, CFNWB



BITTERROOT RIVER AVERAGE MONTHLY STAGE

AT BUCKHOUSE BRIDGE, BBBR

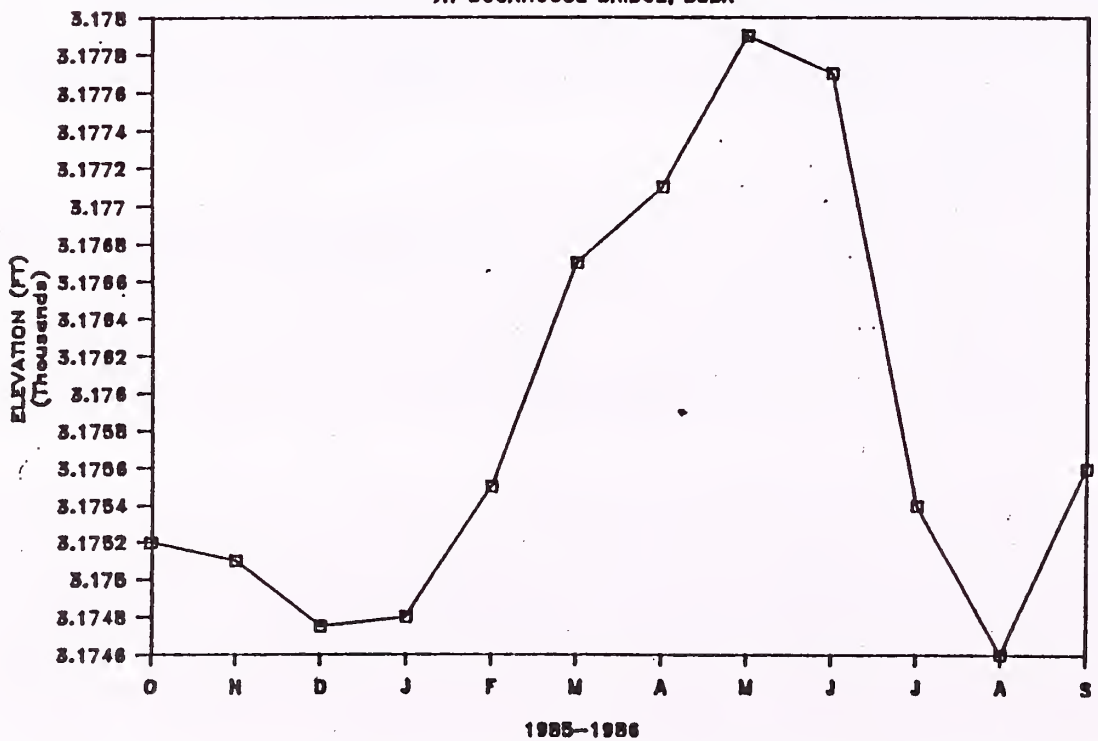


Figure 7.6: Hydrographs showing average monthly stage used in the model for the Clark Fork River (top) and the Bitterroot River (bottom) (Brick, 1987).

TABLE 7.2
1985-1986 Pumping Schedules for
Mountain Water Company Municipal Wells
(gpd)

	MWC1	MWC2	MWC3,37	MWC7	MWC8	MWC9	MWC10
Oct	56307	37	398742	2278655	65	0	62339
Nov	34049	89	604226	636263	49	0	59597
Dec	0	0	348403	581033	162	0	0
Jan	0	0	412968	641031	129	0	182629
Feb	0	0	275565	609965	0	0	0
Mar	0	0	293903	677771	65	0	0
Apr	0	0	746774	655636	65	162	44291
May	618194	50918	1262532	659812	25097	3113	653807
Jun	653791	200184	279307	671618	88194	13355	639984
Jul	503758	161202	1192516	677912	92548	2500	634226
Aug	530081	198329	1115790	621865	103887	13613	647484
Sep	187145	3608	0	655852	81	97	630710
	MWC11	MWC14	MWC16	MWC18	MWC19	MWC20	MWC21
Oct	97	607403	49	81	307	145	113
Nov	25920	574452	81	97	129	145	65
Dec	19049	81	129	145	613	613	226
Jan	680420	586855	0	145	129	62371	35694
Feb	903210	530984	0	0	49	56533	35694
Mar	1004435	557129	65	162	194	37065	145
Apr	968452	567710	81	65	371	160087	97
May	994742	556726	42178	49	40129	364645	304258
Jun	684984	575242	142952	5678	84774	433516	325645
Jul	323887	589178	104307	3016	99420	426178	455339
Aug	986016	594694	182984	9258	190920	516710	904597
Sep	346307	511484	49	65	65	61403	55403
	MWC22	MWC23,24	MWC25	MWC26	MWC27	MWC29	MWC30
Oct	97	265008	10420	49	65	98839	1791
Nov	97	251123	14742	65	65	90920	113
Dec	65	266299	13710	97	162	95791	1016
Jan	65	231207	97	210	49	110662	2304920
Feb	1065	219426	0	65	0	100420	2062322
Mar	6033	250621	920	65	65	119887	2307322
Apr	11710	567710	8420	81	65	134242	2200161
May	16516	326033	82565	523581	11484	192081	2275193
Jun	62194	347307	247065	478629	50291	273145	1566242
Jul	49484	343581	239033	370371	20452	279339	728452
Aug	60533	369820	322420	731984	43920	335355	996274
Sep	162	282431	13500	43629	49	117662	59807

TABLE 7.2, continued

	MWC31	MWC32	MWC33	MWC34	MWC35	MWC36
Oct	2404516	1628129	226	3530806	194	3113
Nov	2323500	1155371	274	3525967	178	65
Dec	2406435	1070435	323	3826613	274	97
Jan	14871	1555742	237758	3031935	161145	355
Feb	4242	1478952	4242	3061774	113	468
Mar	10645	1692774	291	3550806	113	952
Apr	564678	1265435	145210	3023226	6371	12936
May	586420	1783887	752855	1165000	161420	77645
Jun	1765032	2039742	1074580	3475645	65	234936
Jul	2413258	2031677	1050338	4040484	178	303750
Aug	2387984	2078258	1231355	3735161	162	644581
Sep	2356532	1794613	68936	3464193	162	18081

TABLE 7.3
Leakage Values Used in the Model
(gpd/ft³)

Oct	.8	Apr	2.0
Nov	.8	May	5.0
Dec	.3	Jun	5.0
Jan	.3	Jul	1.0
Feb	.8	Aug	.8
Mar	1.0	Sep	.8

MODEL RESULTS

Despite numerous attempts and manipulations to the model, the simulation is still not calibrated to the actual head data. It provides a good, general overview of ground water flow in the valley but is not sufficient for predictive modeling.

Examples of the distribution of heads generated by the model are illustrated in Figures 7.7 to 7.9. Figures 7.10 to 7.11 are hydrographs which illustrate the modeled change in head over time compared to actual measured values at selected locations on the grid.

The transient simulation is not a perfect reproduction of the actual water table. The model more accurately simulates actual heads in some regions of the aquifer than in others. For instance, the hydrograph for MV22 (Figure 7.11) shows the correct fluctuation pattern but the overall elevation of simulated heads is one to two feet higher than actual heads. Examples of other problem areas are shown in Figures 7.10 and 7.11. These hydrographs show simulated heads fluctuating either too much or not enough in comparison to measured heads. Another problem in the model is the head distribution near

OCTOBER

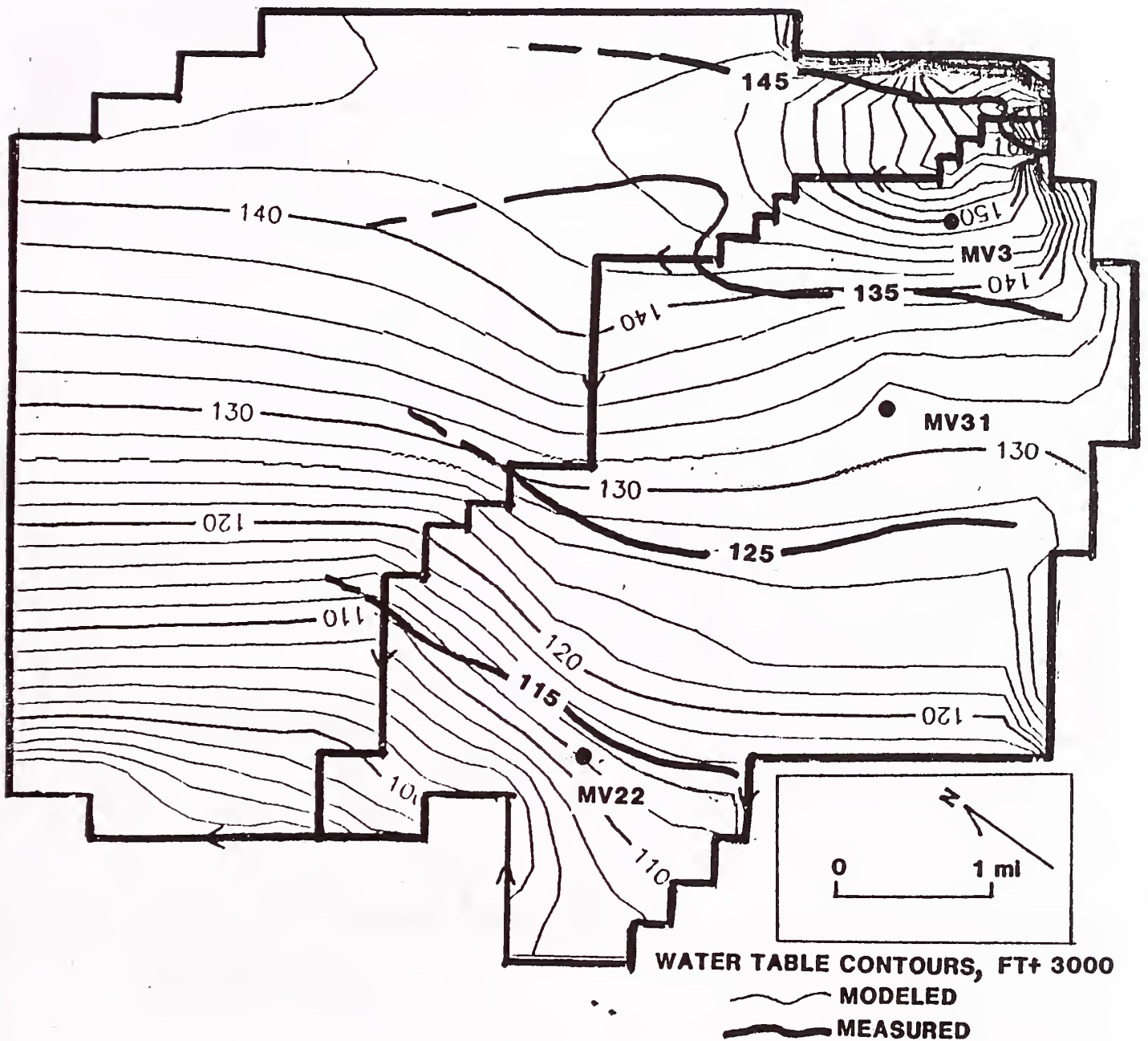


Figure 7.7: Modeled and measured water table elevations, October 1985 (after Brick, 1987).

MARCH

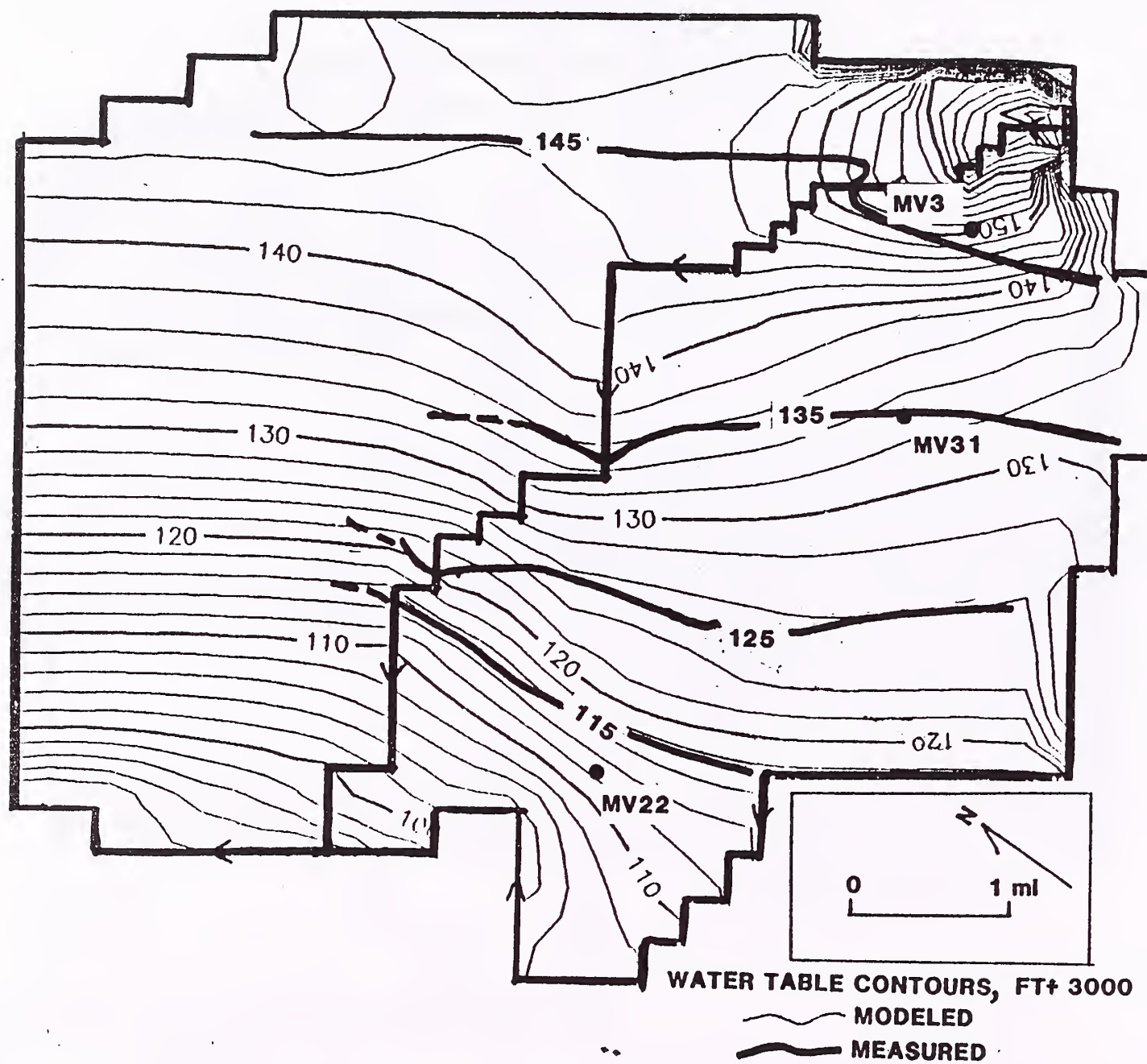


Figure 7.8: Modeled and measured water table elevations, March 1986 (after Brick, 1987).

JUNE

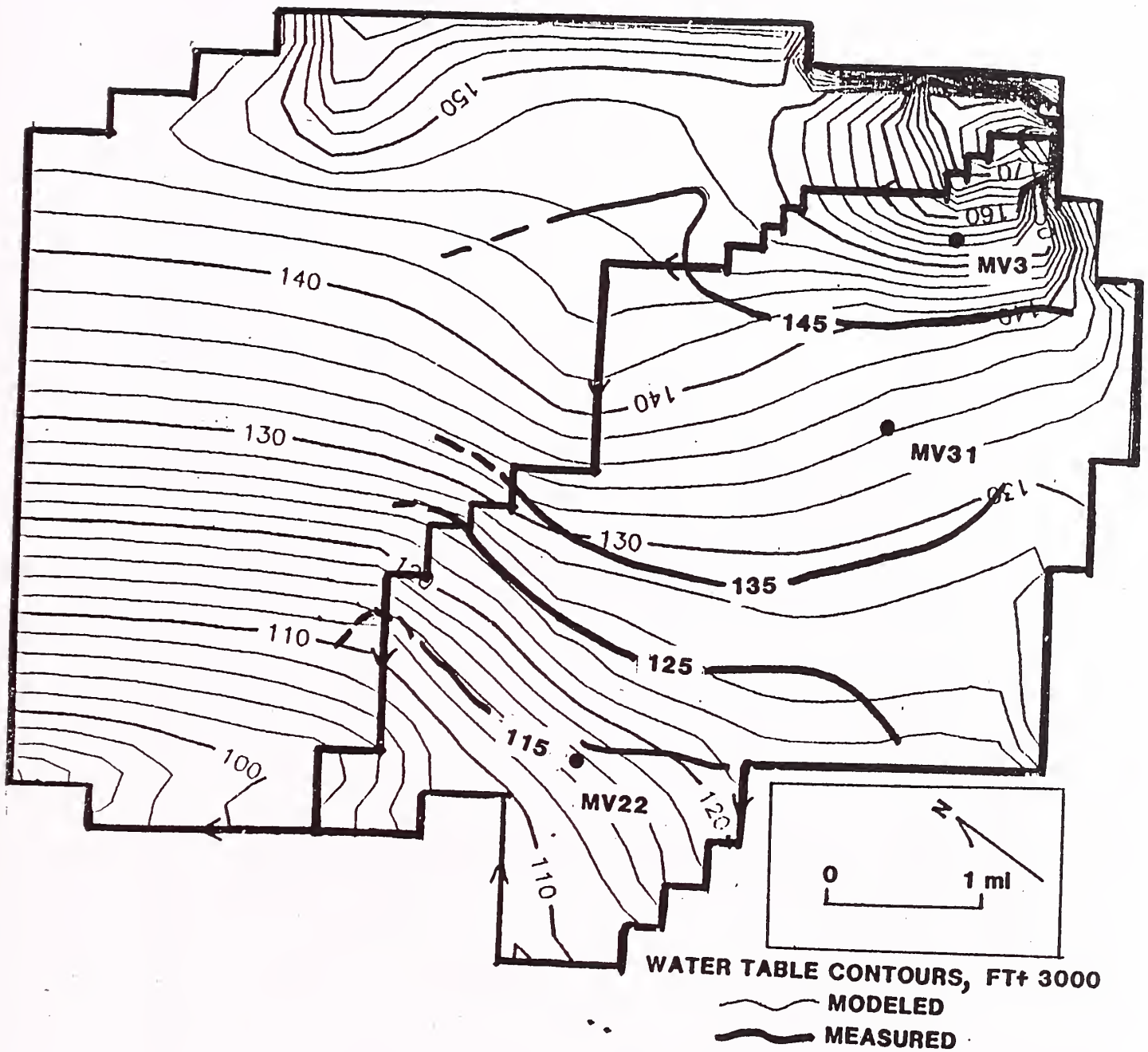
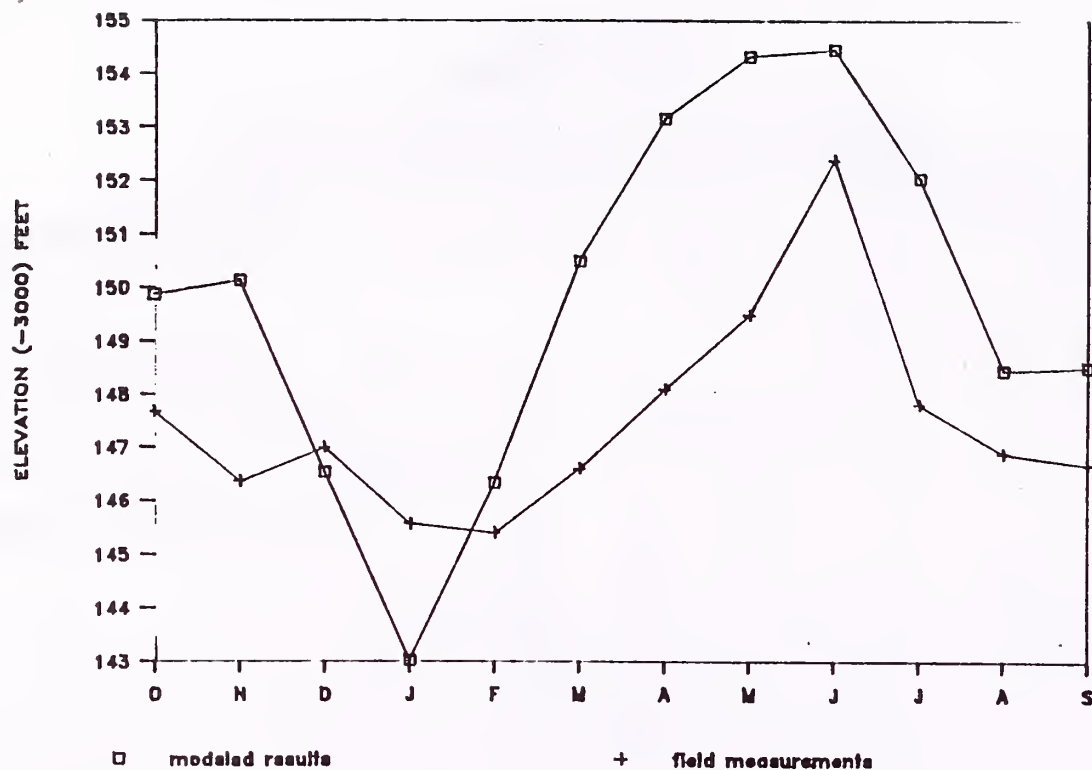


Figure 7.9: Modeled and measured water table elevations, June 1986 (after Brick, 1987).

WELL MV-3



WELL MV-31

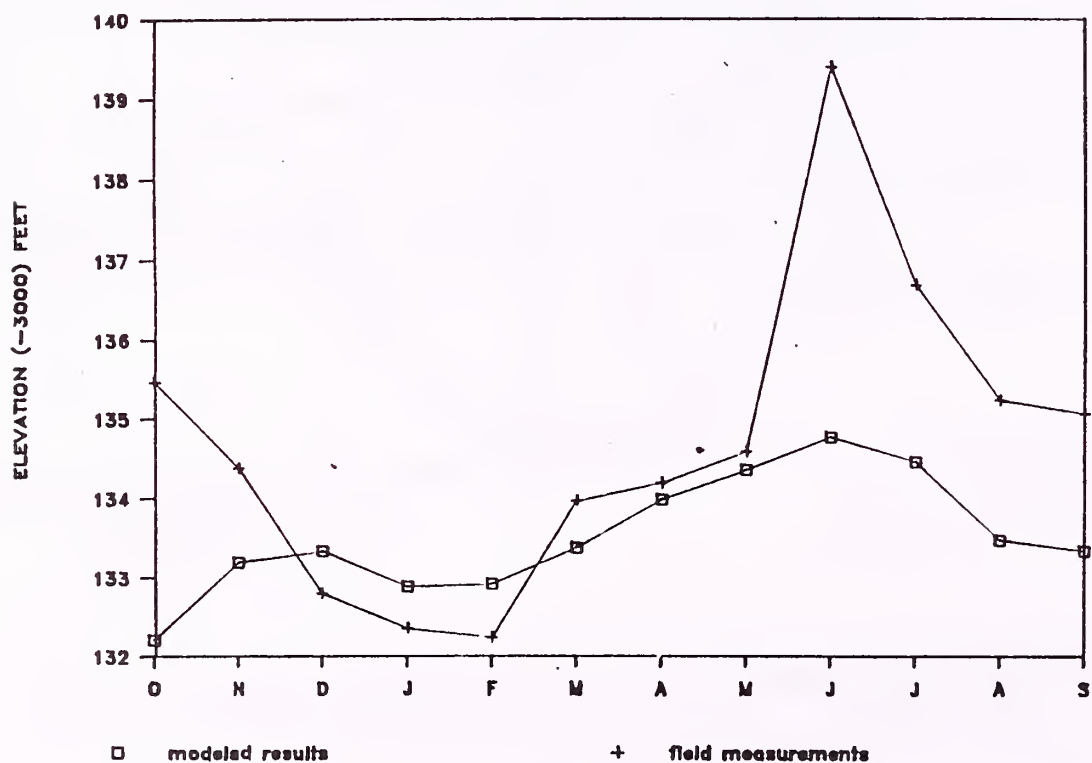


Figure 7.10: Hydrographs showing modeled and measured heads at wells MV3 (top) and MV31 (bottom) (Brick, 1987).

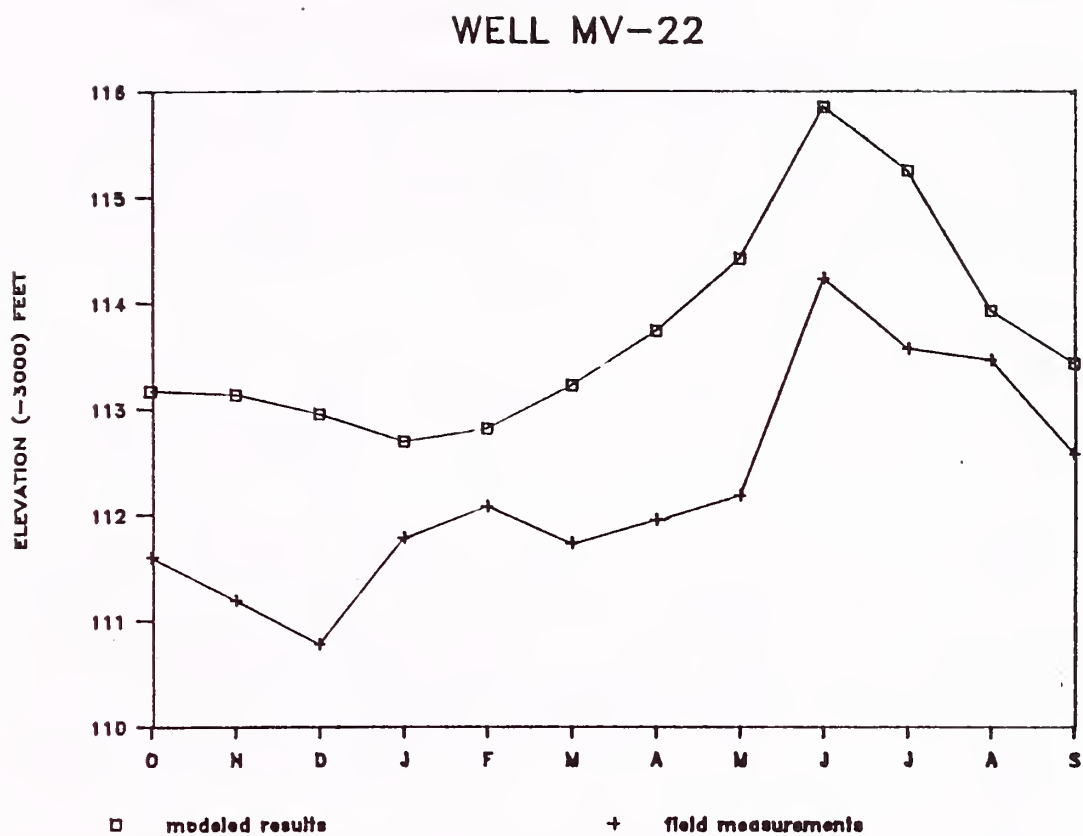


Figure 7.11: Hydrographs showing modeled and measured heads at well MV22 (Brick, 1987).

Grant Creek. Although the model injects more water than is really warranted by the data, the heads in this area are consistently too low.

The spacial distribution in modeled heads matches measured data best in March (Figure 7.8). Modeled water tables for October and June are poor representations of the actual head distribution (Figures 7.7 and 7.9). One of the problems encountered was that the model fails to simulate the wide seasonal and spacial changes in the water table illustrated in Figure 5.5. This figure shows the migration of the 3,135 ft water table contour from June to March, a trend not reproduced by the model.

The model is imperfectly calibrated largely because the necessary input parameters are imperfectly known on a valley-wide scale. The Missoula Aquifer is a large heterogeneous aquifer with many sources and sinks of water. Although many parameters have been quantified for the Missoula Aquifer, more continuous data are needed to effectively use the model. To date, missing data have been filled by approximations. In particular, a better picture of the distribution of hydraulic conductivity is needed. Figure 3.8 shows a wide range of conductivity in the aquifer, however, the actual distribution of the various fluvial sediments comprising the aquifer is poorly known. Morgan's (1986) effort to delineate the distribution of hydraulic conductivity was the most detailed but the problem needs to be considered in more detail. Evaluation of the aquifer using a geologic facies model is needed. However, extensive drilling and sampling of the aquifer would be required to build a detailed model.

Until more data are obtained from the aquifer, the best approach toward modeling may be to work at a different scale. Smaller segments of the aquifer have been modeled successfully (Pottinger, 1988; Peery, 1989) as the problems of large scale heterogeneity are less acute. Smaller models may ultimately be more useful for analyzing specific problems and making specific conclusions. As more information becomes available it should be possible to eventually model the entire valley.

CHAPTER 8

CONCLUSIONS AND RECOMMENDATIONS

The results of this two year study lead to the following conclusions:

1. The Missoula aquifer is stratigraphically complex. It is composed of three units, the first or second of which is not always present. The upper most unit, Unit One, is 10 to 40 ft thick and is composed of interbedded boulders, cobbles and gravel. The middle zone, Unit Two, is composed of up to 40 ft of tan to yellow silt with sand and gravel. Unit Three, the basal unit, is composed of 50 to 100 ft of interbedded gravel, sand and silt.

2. The hydrologic properties of the aquifer reflect site specific stratigraphy and depositional environments. Values of hydraulic conductivity and transmissivity appear to decrease south and southwest of the Hellgate Canyon and Grant Creek area. The hydraulic conductivity of Unit One and Unit Three ranges from 10,300 gpd/ft² to 25,000 gpd/ft². Values for Unit Two average 200 gpd/ft². Transmissivity values for Unit One and Unit Three range from 103,000 gpd/ft to 1,710,000 gpd/ft. Values for Unit Two average 8,000 gpd/ft. Approximate hydraulic properties of the entire aquifer, assuming the aquifer is acting as one homogeneous unit, are a porosity of 0.20, specific yield of 0.12, hydraulic conductivity of 18,200 gpd/ft² and a transmissivity of 1,152,000 gpd/ft.

3. Changes in aquifer storage are indicated by water table variations. These fluctuations reflect seasonal changes in the quantity of recharge reaching the aquifer and in the rates of ground water withdrawal by pumping and by natural discharge. During 1985-1986 and 1986-1987 wells closest to the influent portions of the Clark Fork River, Rattlesnake Creek and Grant Creek showed water table fluctuations of three to 17 feet. Wells located further from these points of recharge fluctuated at a lower amplitude. During 1985-1986, peak water table elevations throughout the valley were higher than peak elevations in 1986-1987. The water table low recorded in late winter was lower in 1987 than the previous year. These valley wide trends appear to have begun in 1983, when climatic conditions apparently changed, resulting in less than normal Clark Fork River spring discharge and aquifer recharge. Also since 1983, the main water producer in the valley, Mountain Water Company, more than doubled its pumping rate in order to increase its production of ground water to supply 100 percent of its needs. A step function decline in water level occurred at those Mountain Water Company wells which experienced the increased pumping.

4. The Clark Fork River is a losing stream and recharges the aquifer from four to six miles of its channel during much of the year. Mass balance calculations show that the river accounts for 90 percent of aquifer recharge. Total aquifer recharge is 15 times greater than

withdrawal from Mountain Water Company wells, Clark Fork Water Company wells and approximately 4,700 individual wells. Based on these data, the apparent valley wide decline in the water table since 1983 is a result of a reduction in recharge caused principally by lower than normal flow in the Clark Fork River.

5. North of the Clark Fork River, the direction of ground water flow is strongly influenced by recharge from the boundary foothills on the north and from the Clark Fork River. Flow in this part of the aquifer parallels the river and moves west until it passes the Reserve Street area, where it turns south to discharge to the Clark Fork River below its confluence with the Bitterroot River. In the area of Missoula south of the Clark Fork River, ground water flows south and southwest to discharge to the Bitterroot River and, seasonally, to the lower reaches of the Clark Fork River.

6. The water quality of the aquifer is good and does not require treatment prior to use in most areas. The water is dominated by calcium and bicarbonate ions, is low in total dissolved solids (less than 500 mg/l) and is similar in chemistry to the Clark Fork River. Wells located adjacent to influent streams reflect the chemistry of these sources of recharge. As the ground water flows away from these recharge areas, total dissolved solids increase through pollution and aquifer dissolution. The presence of chloride and nitrate concentrations which are elevated above natural background levels suggests degradation from anthropogenic sources is occurring. Injection of storm water was found to increase chloride concentrations at the water table beneath storm drains. The disposal of sewage by seepage rings or drain fields appears to be degrading water quality in portions of the valley as both nitrate and chloride concentrations are elevated in areas served by septic systems. Fortunately, concentrations do not exceed drinking water standards. However, coliform bacteria and fecal coliform bacteria have been found in individual water supplies at levels which exceed drinking water criteria. The aquifer is extremely vulnerable to contamination because it is unconfined and consists of generally coarse material.

7. An attempt to numerically simulate the aquifer's complex stratigraphy and recharge-discharge relationships was unsuccessful. The computer model could not be calibrated using field data and then independently verified with a second set of field data. Problems were viewed as being partially attributable to inadequate definition of recharge rates from the Clark Fork River and of the distribution of aquifer properties.

The conclusions listed above imply that the Missoula Aquifer is an aerially extensive, thin, unconfined system which is geologically complex and vulnerable to contamination. It is Missoula's sole source of water and an irreplaceable resource. Protection of the Missoula Aquifer requires continuing long term observation and management. The following recommendations are based on the conclusions outlined above:

1. Maintain a long term water level observation network. Analyses of historical water table fluctuation data were critical in deciphering the relationships between apparent water level declines and causes for such trends. However, previous data collection efforts failed to measure true annual minima and maxima of the water table so trends were difficult to define. Secondly, years of daily water level records extending over a number of years with differing climatic conditions are needed to calibrate and verify a numerical model of the system. The establishment of a water level monitoring network has been initiated as part of this project. Nine wells drilled specifically for water level trend observation were installed. Seven of these wells and well MV31 (MWC7) have been equipped with electrical transducers and electronic data storage systems. The existing system should be expanded by installing similar water level recording devices at the remaining two wells, MV41 and MV42. In addition, water level records for the region north of the Clark Fork River should be reviewed, and one to two wells in this area should be instrumented with similar water level recording systems. MWC wells would be suitable if permission for installation can be arranged. Funding is required to maintain the equipment, collect monthly manual water level readings and to reduce and report the data.

2. Along with a water level monitoring network, a water quality monitoring network should be established. Approximately 30 wells located throughout the aquifer and finished in various aquifer units should be sampled four times a year. Water quality analyses should include gross ions, metals and metaloids, and coliform bacteria. Yearly, selected wells should be sampled for organic analyses, including volatiles, pesticides and solvents. The results of this sampling would be used to identify trends in water quality and provide a baseline from which the effects of point and non-point contaminant sources can be evaluated. Funding is required to pay for water quality analyses, sample collection and equipment, and data reduction and reporting.

3. The development of a numerical model of the aquifer should be continued. Long term management of the aquifer as the sole source of water supply for Missoula and surrounding areas requires the ability to test the effects of increased pumping and changes in recharge rates prior to their occurrence. A calibrated and verified model will provide aquifer managers with such a capability. In addition to water supply management, a model could be used to predict pathways and directions of contaminant migration and to identify sensitive portions of the aquifer which require special management consideration. Developing a computerized model will require additional data for calibration including water level records collected over the last year and better estimates of the distribution of hydraulic conductivity and Clark Fork River leakage rates. Aquifer testing of 60 to 100 wells should be conducted to provide an independent check on the thousands of pumping and drawdown data recorded by drillers. Additional mass balance work to estimate Clark Fork River recharge should be attempted. Funding will be required to refine and improve modeling efforts, to support additional data collection and to maintain and update the model once it is operating.

It is the goal of these recommendation to provide the citizens of Missoula with the facts needed to make educated management decisions regarding the future of their source of potable water. Halting data collection and further work on model development would be short sighted and could lead to poor planning and crisis situations in managing this critical resource.

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